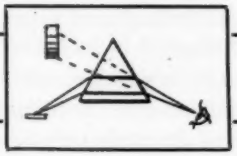
JOURNAL
of the
OPTICAL SOCIETY
OF AMERICA

VOLUME 21
No. 6



JUNE
1931

REFLECTANCE MEASUREMENTS IN THE PAINT INDUSTRY*

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Received March 21, 1931]

Introduction

The importance of an accurate measurement, and if possible, the intelligible specification of the color of paints has been recognized for many years, and the activities of Sub-Committee XVIII of Committee D-1 of the A.S.T.M. during the past ten years have centered in the building up of such a specification. It is the purpose of this discussion to cover, in addition to color, the other optical characteristics of a painted surface or paint material. Such a discussion naturally centers about the measurement of the color characteristics of the reflected light.

Specification of Color

The specification of the color of paint or paint material which is being advocated in the Paint Industry was developed by Sub-Committee XVIII of Committee D-1 of the A.S.T.M., under the chairmanship of Mr. F. P. Ingalls. A brief history of the work of this committee is of value in showing the development of the specification. The early work of the committee consisted largely in measuring various colored materials on the several types of color-measuring equipment available. As a

* Presented at special session of the Optical Society of American on Industrial Color Standards, New York, February 26, 1931.

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result of this work and guided by the report of the Colorimetry Committee of the Optical Society, the committee definitely decided upon the use of a spectrophotometric curve to define color. The work of the committee during the years 1922, 1923, and 1924 on the use of the spectrophotometric curve led to the conclusion that inaccuracies in results obtained on different instruments were due largely to the influence of specularly reflected light. This, in turn, led to the conclusion that an exact specification of the method of illuminating and viewing samples for spectrophotometric analysis was of primary importance. The committee was further strengthened in its belief in the use of the spectrophotometric curve by a test in which several colored paints were reproduced by two paint laboratories working from the formulae and spectrophotometric curves for such paints.[1] This development work, carried on by the committee, together with the gradual increase in the use of the spectrophotometer in the Paint Industry, has led the committee to the point where it has been able to draw up the following specification.

A.S.T.M. SPECIFICATION—"THE COLOR CHARACTERISTICS OF PAINTS IN TERMS OF FUNDAMENTAL PHYSICAL UNITS"[2]

This method determines the color characteristics of a paint in terms of fundamental physical units. The appearance of a painted surface may, however, be influenced by properties other than spectral reflectance, notably, degree of gloss.

APPARATUS

1. The apparatus shall consist of an instrument by means of which the spectral distribution curve of the reflection by a given sample, within the limits of the visible spectrum, may be determined.

2. The spectral reflection curve of the standard reflecting surface shall be known. The flat, even surface of a block of pure magnesium carbonate, if freshly and heavily fumed with magnesium oxide makes a very suitable non-selective standard that is easily reproducible. If this standard is used, it shall be tentatively assumed to have a reflection factor of 98%. If any other surface is used as the standard, its reflection shall be specified.

3. (a) The sample and standard shall be illuminated under identical conditions.

[1] Report of Sub-Committee XVIII, Committee D-1, Proceedings of the American Society for Testing Materials, Vol. 26, page 347, 1926.

[2] A.S.T.M. Standards 1930, Part 2, page 437.

(b) The manner of illumination shall be specified, stating whether the illumination is diffuse or uni-directional. If uni-directional, the angle of incidence shall be specified.

(c) The manner and angle of viewing shall be specified.

4. (a) The calibration of the photometer scale or other intensity measuring unit shall be carefully checked for accuracy, at reasonable intervals, by comparison with an absolute standard.

(b) The accuracy of the wave-length calibrations shall be checked, at reasonable intervals, by a sodium flame or other acceptable means.

Note: This method (measurement of spectral reflectance) serves to specify the color of a painted surface in fundamental physical terms, subject to the limitation that the color may depend upon the manner of illumination. In addition to selectivity of reflectance with respect to wave length, the appearance of such a surface and particularly its changing appearance with different manners of illumination and different angles of view, depends upon the gloss of the surface. The manner of illumination must accordingly be made a part of the specification. Unless it is otherwise specified for some particular purpose for which the measurements are being made, it is recommended that the sample be illuminated diffusely and viewed in the direction normal to its surface. If the purpose of the measurements is to provide a specification of the color of a surface viewed without glare due to gloss of the surface, the specularly reflected light shall be excluded. Where the appearance of a painted surface is to be completely specified, inclusion of degree of gloss of that surface is necessary. In every case it shall be definitely stated whether or not the reflected light measured includes light reflected specularly from the surface of the sample.

PROCEDURE

5. (a) The sample to be analyzed shall be handled carefully to avoid discoloration. The condition of the sample before and after analysis shall be carefully noted and any change in the appearance of the surface shall be recorded.

(b) Readings shall be made at each of various wave lengths of the visible spectrum sufficient in number to establish a reliable indication of the percentage of light reflected by the sample at each of these wave lengths, the number of wave lengths at which the determinations are made to be sufficient to accurately represent, graphically or numerically, the characteristic spectral reflection of the sample.

6. The results obtained shall be preserved as a record.

7. If the sample undergoes a visible change during the analysis, the readings shall be rejected. (See Section 5 (a).)

REPORT

8. The report of the color characteristics of a paint shall consist of the following:

(a) The characteristic spectral reflection in terms of fundamental physical units determined in accordance with Section 5 (b).

(b) The nature of and the reflection factor of the standard reflecting surface employed, as specified in Section 2.

(c) The manner of illumination and manner of viewing as specified in Section 3 (b) and (c).

CURRENT PRACTICE IN THE MEASUREMENT OF COLOR

In the routine grading of paints for color, the eye is universally used and the experienced color grader is an important member of the staff of every paint factory. The eye is considered a perfectly satisfactory instrument for grading color when a standard for comparison is available. However, the lack of constancy of paint standards makes it impossible to use this method as an absolute one. The paint man endeavors to keep his standards either in the form of a painted chip or in the form of a wet, tightly sealed sample of the paint. Experience has shown that these standards, either wet or dry, drift appreciably within a short period of time. Therefore, the chief need in the Paint Industry is for an absolute color measurement which can be used to keep such color standards constant. The spectrophotometer proves to be admirably adapted for such a purpose and is being so used by a number of the larger paint companies. In addition, commercial color laboratories are now in a position to offer their services to the paint manufacturer in checking on and restoring to their original color, such color standards.

There has been very lttle actual specification of color in paint by means of spectrophotometric curves, chiefly because this specification is only a little over a year old. Therefore, most users of the spectrophotometer have restricted themselves to measurements of some of their raw materials and to the maintenance of their color standards. One company whose work is of such a character as to demand unusual constancy in the color of the paint which it produces has applied the spectrophotometer to a broader field and to a greater extent than perhaps any other paint organization. This company is the Standard Textile Products Company, manufacturers of paint-coated cloths for wall coverings and

table coverings. Through the courtesy of Mr. J. B. Davis, plant manager of this company, examples of the routine color analyses, made by this company, are shown here. Fig. 1 represents the analysis of a dry color; both full strength and when let down with white. Fig. 2 represents the analysis made of all white pigments used as raw materials.

Fig. 3 is a reproduction of one of the more elaborate printed wall coverings which this company manufactures. A ground color and four print colors are used in preparing this material. The pattern must be

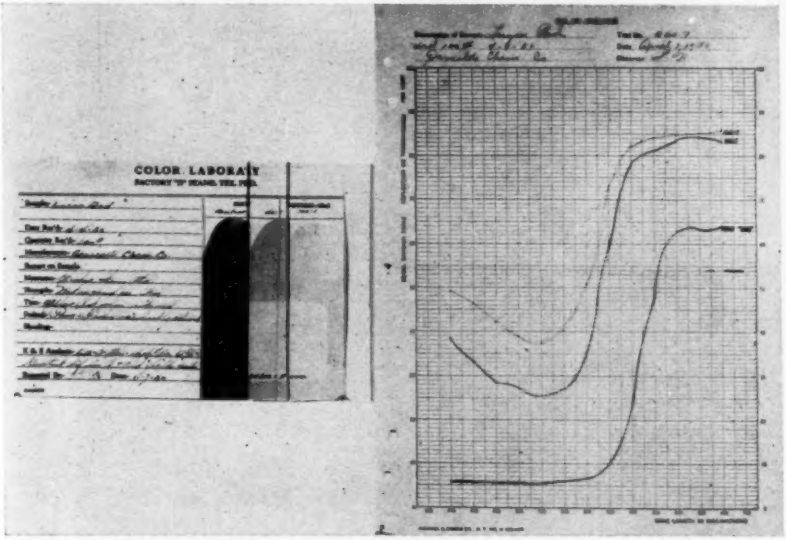

FIG. 1.

reproduced in the factory at least six times each year and must be reproduced within rather narrow color limits. The spectrophotometer is used in the reproduction of colors for successive batches in preference to either wet or dry standards. The record used for such color measurement is shown in Fig. 4; a record of this type is made for the ground color and for the four print colors.

Whenever color measurement is discussed, the question is raised as to whether or not the spectrophotometer can distinguish differences which are just perceptible to the eye. Mr. Davis selected two samples of a wall covering representing the maximum difference in color which is tolerated in their manufacturing procedure. This difference was just perceptible

to the eye; one sample being more greenish than the other. These two samples were analyzed and the spectrophotometric curves are reproduced in Fig. 5 showing that the spectrophotometer can readily distinguish between the two. The marked success of the Standard Textile

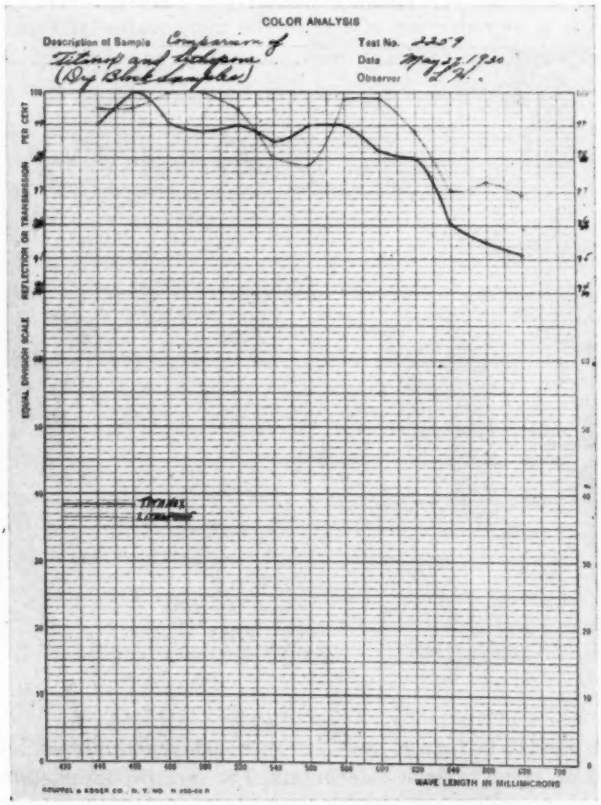

FIG. 2.

Products Company in using the spectrophotometer in a routine way to reproduce color is a further evidence of the correctness of this method of color specification.

At the Standard Textile Products Company and at practically all other paint laboratories where spectrophotometric measurements are being made, the Keuffel and Esser color analyzer is being used. This in-

strument is considered generally satisfactory for routine use and its accuracy is sufficiently high for the present requirements which are placed upon a spectrophotometer. It is, of course, limited in the rapidity with which determinations can be made due partly to the eye strain encountered by the operator. However, even where the volume of work is as large as that at the Standard Textile Products Company, a single operator is able to successfully complete the work.

FIG. 3.

Other spectrophotometers are, of course, available and are equally as satisfactory as the K. & E. color analyzer. At the Bureau of Standards the Koenig-Martin's spectrophotometer is used for routine work. At the Paint Section of the Bureau of Standards, the Appel and Hickson spectrophotometer is in use. A detailed list and description of colorimeters and spectrophotometers available and in use in the paint trade is given by Gardner.[3]

[3] Chapter 11, Physical and Chemical Examination of Paints, Varnishes, Lacquers, Colors—H. A. Gardner, 1930 Edition.

The ordinary spectrophotometer is not entirely satisfactory for the measurement of white or nearly-white paints to distinguish slight differences in color characteristics. For this purpose a modified instrument making use of the principle of multiple reflections has been designed by Dr. A. H. Pfund and is known as the Pfund colorimeter.[4] Using color

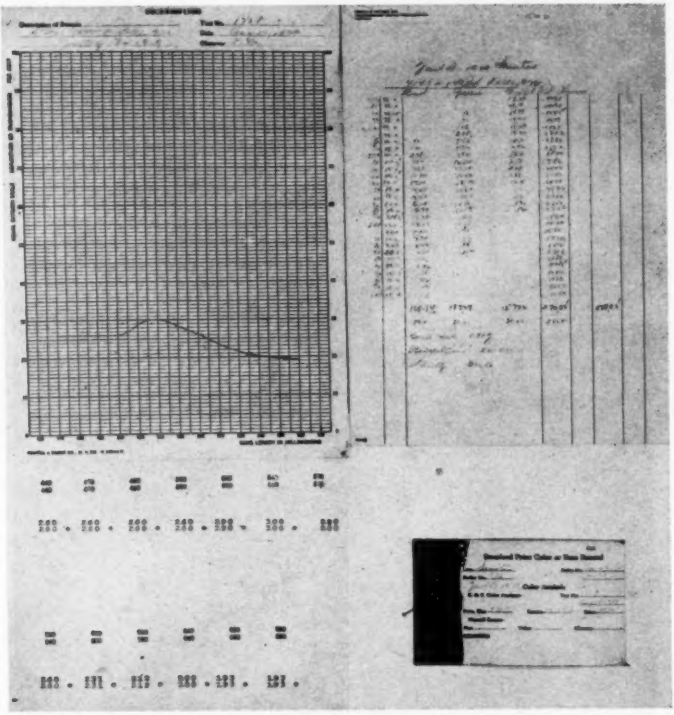

FIG. 4.

screens to define wave length, this colorimeter determines the spectrophotometric curve and distinguishes between materials in the near white range with an accuracy greater than that of the ordinary spectrophotometer.

While many tests on paints and paint materials have been conducted using the more recent photo-electric and recording types of spectro-

[4] *The Colorimetry of Nearly-white Surfaces* by A. H. Pfund, J. Frankln Inst., *189*, 371; March, 1920.

photometer, these results have not been entirely satisfactory nor have they in general shown the accuracy of the ordinary spectrophotometer. From the standpoint of measuring the color characteristics of paints with such instruments, it is probable that Mr. H. A. Gardner of the Gregg Memorial Laboratory, Institute of Paint & Varnish Research,

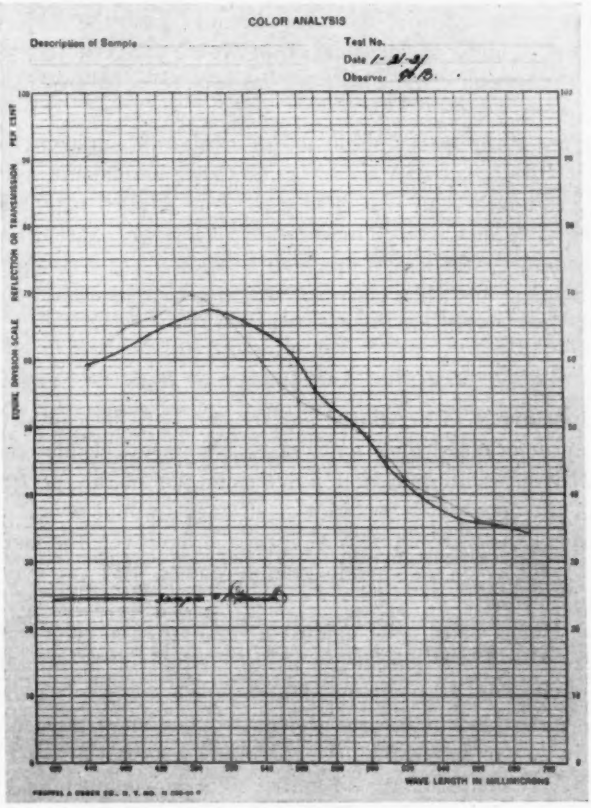

FIG. 5.

has done more work than any other. It is his opinion that such instruments in their present form are not as satisfactory as the regular spectrophotometer but he expresses himself as being "keenly appreciative of the possibilities of these instruments, believing that ultimately they will be developed to become a most useful part of every color laboratory."

From the standpoint of the Paint Industry each of these instruments is at present subject to one or both of two limitations: first, accuracy (which should, on a routine basis, equal that of the ordinary spectrophotometer) and second, initial cost. The value of the spectrophotometer in maintaining color standards; its ability to measure differences in color which are considered tolerable by the paint man; and its general use in the measurement of the color of paints, form the subject of considerable work under the auspices of the New York-New Jersey Paint & Varnish Production Club. This work has been reported by Messrs. Paul and St. George.[5]

In the use of the spectrophotometer for color measurement of paints, there is a distinct need for a more exact, more permanent, and a more practical standard than that now used. The scraped magnesium carbonate block or such a block fumed with magnesium oxide, while generally satisfactory, still leaves much to be desired. A secondary standard, such as a stable white glass, not sensitive to light, would seem to be most practical, and insure greater permanency.

FACTORS DETERMINING APPEARANCE OF PAINTED SURFACES

The appearance of a painted surface can only be completely and accurately determined by a series of measurements. Under conditions of perfectly diffuse illumination, a determination of the spectral distribution of the apparent reflectance at all angles would give a complete measurement. As a more practical approach, however, the factors considered by the color matcher in grading paints with the eye, will be considered.

In matching a paint color against a standard, the color matcher is rather exact in his requirements as to method of illumination and method of viewing. Whenever possible the north skylight is used and the sample is viewed at a number of different angles, all of them such as to exclude, in so far as possible, the specularly reflected light. The color matcher, therefore, attempts to match color independent of the gloss characteristics of the surface. To completely specify the appearance of the painted surface, he considers it necessary to consider the gloss as a separate factor and in determining this factor, the sample is viewed at such an angle as to obtain the maximum amount of specularly reflected

[5] *The Application of Spectral Distribution Determinations to Maintenance of Factory Color Standards*, by M. Rea Paul and J. P. St. George, New York-New Jersey Club, Circular No. 356, page 848, dated November, 1929. *Color Control in the Paint Plant*, New York-New Jersey Club, Circular No. 370, page 419, dated October, 1930.

light. In view of this distinction made by the paint man in the grading of the appearance of a painted surface, it is considered that three factors are sufficient to specify the appearance of a painted surface with sufficient exactness for practical purposes. They are:

1. The amount and spectral distribution of the diffusely reflected light.

2. The amount of the specularly reflected light (the gloss).

[For an exact determination, the spectral distribution of the specularly reflected light should be obtained. For practical purposes, the variation due to absorption characteristics of the vehicle, size of surface imperfections, etc., can probably be neglected.]

3. The total (integrated) reflectance.

Considering these factors in order, it is apparent that the first is the one considered by the color matcher when he views the paint sample in diffused daylight at all possible angles. In the development of the color specification given above, it was recognized that in so far as possible the spectral distribution of the light reflected by a paint should be kept independent of the gloss and the suggested method of diffuse illumination with normal viewing is an attempt to attain this end. Such a method of illumination and viewing, however, can be made to include varying amounts of the specularly reflected light, depending upon the size of the opening through which the sample is viewed. To have the determination restricted to the diffusely reflected light, it is necessary to have the opening comparatively large so that no specularly reflected image of the sphere wall is reflected into the photometer. A more certain but slightly less accurate method of excluding specularly reflected light is the use of a directed beam for illumination, for example, normal illumination with 45° angle of viewing. This method permits a greater intensity of illumination and is generally preferred in the new photo-electric type and recording spectrophotometers. There is considerable difference of opinion on the matter of illumination and viewing of samples for color determination, but the ideal to be attained is a method by which specularly reflected light is entirely excluded.

The second factor to be measured, namely the amount of specularly reflected light, should, in turn, be as independent of the body color as is possible. There are many methods of measuring this quantity, most of them determining it by difference between total reflectance and diffuse reflectance.[6] A simpler method is that employed in the Ingersoll glari-

[6] Ries & Gilbert, *Gloss and its Quantitative Measurement*, Proc. A.S.T.M., *30*, part II, 911; 1930.

meter,[7] where the polarization of the specularly reflected light is used to differentiate it from the diffusely reflected light. This method, while generally satisfactory, is affected to too great an extent by the color characteristics of the diffusely reflected light. An instrument has recently been described by Pfund which makes possible the measurement of the specularly reflected light independent of that diffusely reflected; it is known as the Pfund glossmeter.[8] This instrument is not absolute but determines the gloss relative to a standard such as a piece of polished glass. However, it is quite accurate and extremely simple in operation. It would seem, at the present time, that this instrument is the one most satisfactory for evaluating the second factor independent of the first.

The third factor is of particular interest in specifying a painted surface in that it should give a measure of the efficiency of that surface in reflecting light. It, therefore, is of value to the illuminating engineer and to the architect where the reflecting efficiency of paints is a real factor. Accurate reflectance measurements are rather difficult to obtain. Objections can be cited to integrating types of instruments such as the Taylor reflectometer. A measurement made under conditions of diffuse illumination and normal viewing through an aperture of minimum size can also not be considered perfect. The inaccuracies of both measurements are, of course, greater, the more pronounced are the gloss characteristics of the surface measured. The only exact method for measuring total integrated reflectance would seem to be that of McNicholas[9] in which diffuse illumination is used. Apparent reflectance is measured at all possible angles and the total reflectance measurement is obtained by integration. The McNicholas measurement is both long and tedious and requires rather elaborate equipment. There is a distinct need for a simple instrument which will measure the total integrated reflectance of a surface with a high degree of accuracy; regardless of the gloss characteristics of the surface to be measured.

Another problem of particular interest from the standpoint of the lighting engineer, is that of determining the relative efficiency of diffusely reflected and specularly reflected light in interior lighting. More exactly, will a paint having an extremely glossy surface have the same lighting efficiency as another paint of the same total reflectance, but having an extremely diffusing surface?

[7] L. R. Ingersoll, *Glarimeter*, Journal Optical Society, *5*, 213, 1921.
[8] J.O.S.A. *20*, 23; 1930.
[9] Bureau of Standards Journal of Research, *1*, 29; 1928.

In the formulation and manufacture of a paint, the first two factors are of prime importance. The first factor (body color) will be governed by the type and amount of white and colored pigment incorporated in the paint. The second factor will be determined by the degree of perfection attained in incorporating the pigment in the vehicle and in the type of pigment and of vehicle used. The third factor, while giving the paint man a check on the specification of his material, is of primary importance because of its value to the user of the paint, particularly in determining its illuminating efficiency. The ideal instrument would be one on which all three factors could be quickly and economically determined.

Acknowledgment

For assistance, suggestions and use of materials in the preparation of this paper, the writer is indebted to Messrs. G. S. Haslam and D. L. Gamble, The New Jersey Zinc Company; Mr. J. B. Davis, Standard Textile Products Company; Dr. A. H. Pfund, Johns Hopkins University; and Mr. H. A. Gardner, Institute of Paint & Varnish Research.

SPECTROPHOTOMETRIC MEASUREMENTS IN THE DYESTUFFS INDUSTRY*

By Carl Z. Draves

[E. I. du Pont de Nemours and Co., Inc.
Wilmington, Delaware. Received March 21, 1931]

We are met here to discuss the measurement of color and the use of color-measuring instruments in industry. I shall endeavor, as my part of the discussion, to point out how spectrophotometric measurements are useful in the manufacture, standardization, sale and use of dyestuffs. I shall also endeavor to point out those purposes for which direct visual examination is more advantageous than the spectrophotometric method, for there are some who, in their enthusiasm, would employ a spectrophotometer for purposes which can be accomplished more simply quickly, cheaply, and just as satisfactorily without an optical instrument.

If I seem to be rather reactionary in my attitude toward certain phases of spectrophotometry, please remember that I am trying merely to keep my feet on the ground at a time when so many want to jump at the prospect of replacing personal knowledge, experience, skill and visual acuity in color discrimination by automatic machines for the selection of dyes and the matching of colors. It seems to me from my contact with numerous inquiries which reach our Company from consumers of dyes—and they come from a great diversity of industries—that there is an overemphasis with regard to the possibilities of spectrophotometry for commercial purposes at the present time, just as we have overemphasis of so many things in a progressive age. To counteract any implication, however, that I may be unsympathetic with the use of the spectrophotometer may I be excused if I say that I was responsible for the adoption, five years ago, of the spectrophotometer as an aid for routine testing and for research by the only dyestuffs manufacturer in America who, up to the present time, has made any extensive use of a spectrophotometer. In this work I was merely following the way which had been so thoroughly blazed by our United States Bureau of Standards.

Spectrophotometric measurements have proven useful to our Company, both for routine testing and for research. But the appreciation of this usefulness has not come in a week, or in a month, or even in a year to those who might use the results. It should be realized that it requires time for the spectrophotometric method to prove its value and to be

* Presented before the Optical Society of America in New York City on February 26, 1931.

appreciated by plant and research chemists. Only those methods can survive in industry which, after thorough trial, are found to give the most useful results at the least expense.

It was in 1926 that the du Pont Dyestuffs Department first adopted the spectrophotometric method of testing dyes in solution for the routine standardization of commercial lots of dyestuffs for strength. Although the usefulness of the spectrophotometer for this purpose has been pretty well covered in a paper which was presented before the American Association of Textile Chemists and Colorists,[1] it is appropriate to give a few generalizations upon that topic here and now.

If commerical dyes were chemically pure substances containing no colored impurities and never were shaded, but were merely diluted with salt or some other colorless substance, then the spectrophotometric method for the determination of strengths would be sufficient in itself. Since, however, only some dyes are what might be termed chemically pure and since the proportion of colored impurities and the proportion of shading color—if any—and the affinities of these things for the fiber may vary, it is evident that the spectrophotometric method of testing dye solutions for the determination of strength must remain secondary and auxiliary to the dyetest. In practice it has been found that the usefulness of spectral data for strength determination, or, to put it in another way, the relative concordance of actual dyeing strength and the spectral strength of the solution, is dependent upon the uniformity of production of the dye. In our own plant so much progress has been made in improving the quality of intermediates and in stabilizing processes over the past five years that the present agreement between actual dyeing strength and spectral strength is really remarkable. On the other hand, when we come to compare samples of our present production with our own production of seven or ten years ago, or to compare our dyes with dyes made by other manufacturers under different conditions, the concordance between spectral absorption figures and actual dyeing strengths is not so good. We see, therefore, that it requires judgment and constant experience with a given type of production of a dye by those responsible for standardization to make the best use of spectral absorption data as an aid in turning out successive lots of dye which have exactly equal dyeing strength for a given kind of fiber.

Formerly, we employed the titanous chloride titration method of analysis wherever it was applicable as an auxiliary method for the

[1] Draves, Am. Dyestuff Rptr., *17*, 43; 1928.

standardization of dyes for strength. That method was gradually and completely displaced, however, until now it is used only for the analysis of intermediates. The reason for the abandonment of the titanous chloride titration was that the spectral method is quicker and easier, it can be applied to many more dyes and for commercial dyes the spectral strength more frequently checks the dyeing strength because colored impurities have less effect on the spectral absorption value than the principal dye component. It may be said, therefore, that the estimation of a value to represent the dyeing strength of a commercial dye without making a dyeing can be made more accurately from a spectrophotometric examination of a solution of the dye than from a titanous chloride titration of such a solution. Although the precision, or reproducibility of results, is better with the chemical titration, the dye manufacturer is more interested in an accuracy of 1% than in a precision of 0.1%.

Any dyes which can be brought into clear solution can be satisfactorily tested by the spectrophotometric method. As a solvent for direct and acid dyes we employ distilled water with 25 cc of a half molar acetic acid-sodium acetate mixture as a buffer because water is less expensive and easier to work with than other solvents. Mr. W. C. Holmes[3] has recommended 90% alcohol for routine work because the use of alcohol avoids anomalous concentration effects and because the basic dyes in alcoholic solution do not tend to stick to glass surfaces. However, within the differences in strength encountered among commercial dyes, Beer's law is sufficiently valid with aqueous solutions and the basic dyes can be kept from sticking to glass surfaces by the use of acetic acid in solution with the dye. The free bases of the basic dyes are dissolved in strong acetic acid and the spirit soluble dyes with denatured alcohol. In a few instances, benzol or gasoline is employed. The vat colors are dissolved in concentrated sulfuric acid when they do not contain carbonizable material, such as sugar. Although satisfactory results can be obtained with the sulfur and vat dyes which have been vatted in the same manner as for dyeing, we do not ordinarily determine, spectrophotometrically, the strengths of dyes which need to be vatted because the time and labor involved in bringing them into solution make the cost of a determination too high for use.

It is important in the determination of the strengths of commercial lots of dye with a spectrophotometer to use methods which are very simple and at the same time foolproof so that, although the cost is low,

[3] Holmes, Am. Dyestuff Rptr., *15*, 247; 1926.

great reliance can be placed upon the results, even when the tests are carried out by non-technically trained help. For the simplification of calculations, the Keuffel and Esser color analyzer employed in our work was specially calibrated in logarithmic units because dye concentrations are proportional to logarithmic readings. Furthermore, the size of the original weighing and the size of the aliguot portion taken for second dilution are so regulated that a reading of approximately 1.00 in logarithmic units is obtained because readings of absorption can be made most accurately at about 1.0 and also because calculations are simpler under those conditions. Although some consideration at first was given to the possibility that it would not be necessary to make and re-run a solution of the standard prototype each time an unknown strength was determined, it was finally decided that the gain in assurance and accuracy far offsets the slight additional work involved in re-running the standard. When the standard is re-run each time, the accuracy of the relative strength of an unknown in terms of the standard is not influenced appreciably by a slight error in the adjustment of the instrument. Besides, any gross error in weighing is caught up instantly because, if a reading close to 1.00 is not obtained for the standard, then a wrong weight must have been taken in weighing both standard and unknown.

For quick and easy work with dye solutions the type of cell is very important. Screw end cells are strongly to be condemned in spectral absorption measurements because with them it is too easy to encounter errors from squeezing dirt into the solution when the ends are screwed on. Adam Hilger of England offers for sale a cementless glass cell with open top which is certainly a very great convenience. This type of cell really saves hours of work each day because it is so easily filled and because the faces are so easy to keep clean.

Another important point in connection with the spectral absorption measurements of dyes for strength is that comparisons of strength can be made so much more quickly by reading each dye solution only at the maximum of absorption that it is a great waste of time to read the whole absorption curve. Furthermore, readings taken at the maximum of absorption actually check the dyetest better than the areas under the complete absorption curves. I can not agree, either practically or theoretically, with those who have recommended reading the whole curve.[3]

[3] Ind. Eng. Chem., *18*, 627; 1926

The reproducibility of results in the determination of the strength of a sample of dye in comparison with a standard by the spectral absorption method is quite satisfactory. When the maximum of absorption is from 480 to 660 millimicrons we attain an accuracy which corresponds to an average deviation of about 1/2%. For yellow dyes which we arbitrarily read at 455 or 460 millimicrons, the average deviation of a strength determination is about 1%. Although our Keuffel and Esser instrument was specially designed to give greater illumination for transmission measurements, we really need another instrument which would give us greater intensity of illumination in the violet. The slit width of our instrument is 0.25 mm.

Although it is true that the relative hue of a charge or lot of dye in comparison with standard can be more or less determined by a comparison of the complete spectral absorption curves of the solution, or more simply still by a comparison of readings about 50 to 75 millimicrons on either side of the maximum, we have found it quite impractical to determine the relative hue with a spectrophotometer in the routine standardization of dyes. The exact color of a lot in comparison with a standard can be determined so easily and quickly by direct comparison of dyed skeins that it is really ridiculous to attempt to determine the relative color from spectral absorption measurements of solutions of standard and lot.

Theoretically, the proportion of two known dyes in a mixture can be calculated from the spectral absorption curve of the mixture. Practically, however, we doubt if the method will ever be of anything more than theoretical interest because, first, too much work is involved in fooling with such determinations; second, slight errors or slight amounts of impurities introduce a relatively large error; and third, the correct result can be obtained without question by a series of dyeings. On the other hand, however, when the proportion of two or three dyes in a mixture has been determined from dyeings, a spectral determination of the strength of the mixture in solution has some value.

It frequently has been suggested to us that the spectrophotometer be used for the examination of dyed skeins or dyed piece goods for accurate estimations of the dyeing strength and relative color of samples of dye in comparison with standard. (The dyer always uses the term "shade" when he means "color.") Anyone who has seen a dyetester at work, however, will realize at once how impractical it would be for routine work in dye comparisons to examine dyed material with a spec-

trophotometer—even with the automatically recording types. The dyetester would have a record of the color and strength of the lot in comparison with standard before the spectrophotometrist could even have the sample mounted for examination. The dyetester can make up his mind in one minute how strong the lot is, and how far off "shade." Furthermore, from long practical experience he can tell in a few seconds how much "shading" color is required to make the lot like standard, or whether to mix, let us say, a charge which is redder than standard with a charge which is greener than standard to obtain a lot of blue dye exactly like standard.

Both in the daily newspapers and in the scientific journals the statement is so often made that small differences in color can be distinguished much better with a spectrophotometer than by direct observation with the human eye, especially with those spectrophotometers which contain photoelectric cells. Such statements, which are made without any quantitative consideration whatsoever of the sensitivity of the human eye to differences in color, should not remain unchallenged. When a piece of wool was dyed with 1% of Du Pont Tartrazine 0 on the weight of the fiber, a full, rich, bright yellow was obtained. When a series of dyeings was made with the same amount of yellow and with increasing amounts of the bright red dye, Du Pont Crocein Scarlet Concentrated, it was found that 1/5000% of the red on the weight of the fiber could be quite definitely distinguished with the yellow because it made the yellow dyeing slightly redder in hue, whereas 1/10000% of red was not always definitely distinguishable. The reflection of the pieces dyed with the same amounts of the yellow dye and with increasing amounts of the red dye (none, 0.0001%, 0.0002%, 0.0005%, 0.001%, 0.002%, 0.005%, 0.01%, 0.02% and 0.05% of red dye), was measured at 510 millimicrons where the red has the most effect on the reflection. These reflection values were then plotted against percent of red dye. By drawing a smooth curve through the points it was possible to calculate, from the slope of the curve near the origin, the effect of 0.0002% of red on the reflection value at 510 mμ, even though the difference in reflection for such a small amount of red was smaller than could be determined directly with the spectrophotometer. It was found in this manner that 0.0002% of red dye, the effect of which on the hue of the yellow was definitely distinguishable with the naked eye, caused the reflection at 510 mμ to decrease from 22.908% to 22.898%, or by 0.01%. The effect of the red dye on the reflection in other parts of the spectrum we know was much less because that particular red has the most effect at 510 mμ.

We see, therefore, that if the difference in hue between the two dyed samples had been determined from spectral reflection measurements, it would have been necessary to have had an absolute accuracy throughout the whole spectrum of 0.01% in reflection to have accurately defined each color. The width of a line on a scale on which 10% is 1/2 inch would be at least 0.2%. From these sketchy figures it can be appreciated how difficult it would be for an automatically recording spectrophotometer to distinguish the slight differences in color which are evident to the dye. And in stating these conclusions we have omitted to mention that an observer is able to appreciate the color of a fabric with the naked eye regardless of slight and local variations in the gloss and in the structure of the fabric, factors which markedly affect spectral reflection values.

The experiments given above to obtain an idea of the sensitivity of the eye were repeated using small amounts of red dye alone on white wool fabric and also small amounts of violet dye alone on white wool. Small amounts of the violet were likewise dyed along with 1% of the yellow. It was found that smaller amounts of red or violet dye could be detected on the white wool than on wool dyed simultaneously with yellow. Although no attempt will be made here to give all the data, they all pointed to the same conclusion; namely, that the naked eye can definitely appreciate differences in the color of dyed fabrics which correspond to reflection differences of only approximately 0.01%. It must be remembered in this discussion that the naked eye can not appreciate such small differences of color when they are caused by using very slightly different amounts of *exactly the same sample of one dye alone.*

It can not be too strongly emphasized that the most characteristic property of a chemically pure dye, that property which most certainly identifies a dye among other dyes, is the spectral absorption curve of the dye in a standard kind of solution under standard conditions. For this reason, the best and most certain method to characterize any dye in distinction from other dyes is to give its spectral absorption curve. As a matter of fact, although the whole curve is best, a few characteristic points on the curve, especially the absorption values at the maxima and minima of absorption, are sufficient for certain identification. Therefore, as a method of identification of dyes, there is no question but what the spectrophotometer is by far the best for chemically pure samples. And usually, if the dye is not pure, it can first be purified by chemical means. For these reasons, spectral absorption curves are of value in

research in the field of dyes for characterizing dyes for patent purposes and for the identification of unknown and strange dyes by comparison with dyes which can be built up in the laboratory from known intermediates to have a known structure. Where chemical tests fail, the spectrophotometer must always be the final and most certain authority for the identification of purified dyes. Also, one of the best methods to determine the course of purification of a dye is by the spectrophotometric method. When successive purifications cause no further change in the spectral absorption curve of the dye, then it is certain that all colored impurities have been removed. Sometimes, on the other hand, it is valuable to be able to separate and identify the colored impurities themselves. The spectral method is much more accurate for the determination of the simpler colored impurities in dyes than the capillary test with filter paper.

One of the things a selling organization in the dyestuffs business must do every day is to identify a number of unknown products, often mixtures, which have been offered or sold to dye consumers by competitors. One might think from what has been said, that a spectrophotometer would be valuable for this purpose. It is true that a spectrophotometer may be used to advantage for this work when a particularly difficult problem is presented, as outlined above. Under ordinary circumstances, however, the man of experience in a few minutes can identify a dye or mixture of dyes by a few spotting tests of the dye blown out on wet filter paper, using a few common chemicals. Here again we must be careful that we do not, in some instances, go to a longer method with the spectrophotometer when the identification can be made in a few seconds with a few spotting tests even when the sample is a mixture. On the other hand, when simple chemical tests fail, recourse *must* be had either to the spectrophotometric method or to the very long and difficult method of identification of the decomposition products from a complex dye.

An interesting field for investigation in which only a very little, comparatively, has been done, is the correlation of structure with the spectral absorption curves of dyes in solution. Some of our research chemists in building up new dyes have found spectral absorption curves valuable and instructive in their work. These men file away both dyed swatches and spectral absorption curves along with the structural formulae of the dyes. The practical use of spectral absorption curves as an aid in devising new dyes, however, is in its infancy.

Those dyestuffs which are not used on fabrics but which are employed for coloring liquids, such as gasoline, or for coloring films and filters for photographic purposes, are most easily standardized entirely for shade and strength with spectral absorption curves. Here again it is usually sufficient merely to obtain absorption values only at the maxima and minima of the curves.

There are some, as for example those in the gasoline companies, who determine the strengths of dyes which are used in solution by means of a Duboscq Colorimeter. Anyone knows, however, that when there is a slight difference in color, the strengths obtained with a colorimeter can easily vary by as much as 20%, depending upon the depth of layer or upon the concentration used for comparison.

An interesting use of the spectrophotometer is for the study of dyeing rates, or rates of exhaustion of dyes on textiles. The spectrophotometric method offers the quickest and simplest means to determine the amount of color left in solution at regular intervals. This method is particularly good for this purpose because 5 cc samples can be removed from a comparatively large volume, such as 800 or 1000 cc, without appreciably changing the total volume of the dye liquor. By this method, quantitative studies can be made of the effect of pH, salt, temperature and retarding agents on dyeing rates.

It has been shown by Brode[4] and others that the spectrophotometer can be employed for the accurate determination of pH values with indicators. Although the method will undoubtedly prove of value in research, especially in the study of the dissociation constants of indicators, I believe that the spectrophotometer will never find extensive practical use for the routine determination of pH values. When greater accuracy is desired than can be obtained by comparison with known buffers and indicators in a comparator, recourse will probably be had to electrometric measurements. Electrometric measurements of pH are quite simple for most people and they possess the advantage of being determinable in highly colored solutions in which indicators can not be employed.

There is a field of usefulness for spectrophotometric measurements from which I expect great things. I refer to the determination, by means of spectral reflection curves, of the degree of change undergone by dyed fabrics when subjected to destructive agencies, such as light and washing. One of the important functions of our laboratory is to determine and record the relative fastness properties of dyes to those various destruc-

[4] Brode, J. Am. Chem. Soc., *46*, 581; 1924.

tive agencies. In this work, when a change is barely perceptible to the eye, it is sufficient merely to say that the change is a trace. When there is a large loss of strength (by "strength" is meant depth of color, or amount of dye on the fabric) and more often when a change of hue accompanies the loss in strength, the total change in color is expressed by such indeterminate expressions as "appreciably," "much," and "very much." A "much" one day may be "very much" to the same observer the next day when he happens to have indigestion. At present, when there is considerable change in a dyeing upon exposure to a certain destructive agency, the fastness rating of that dyeing in comparison with others of entirely different color is subject to much argument and confusion. For this work it would indeed be a distinct advantage to use spectral reflection curves to show the change upon exposure to a destructive agency. Of much greater value, however, would be a single numerical value which would express the perceptible number of color steps between the original and the exposed sample so that the relative fastness of different colors which fade in different ways could be accurately compared.

There is no question with regard to the usefulness of numerical data for expressing the change of a color in perceptible color steps. I wonder, however, if we properly appreciate the magnitude of the task of obtaining the data for such determinations. From thirty to fifty fastness tests are made for one dye and the whole series of tests must be made not only for every product which the manufacturer puts on the market but also for every product which he has under consideration for the market. Now, the color of a dyed fabric is reasonably well determined only when the reflection data are as accurate as can be obtained under the best conditions, assuming that the effect of the structure of the cloth and the manner of illumination can be satisfactorily handled. To obtain such data at the present time and to make the necessary calculations would certainly require several hours for each fastness property. If an experienced man can record visual observations covering 30 to 50 fastness tests in an hour and a half, you can appreciate how impractical it would be to take several days for the same work merely to express the results numerically. If the time required to obtain spectral reflection curves accurately and to calculate the colors and the changes in color could be shortened by the use of automatic instruments to eight or ten minutes the dyestuffs industry would gladly adopt such automatic instruments. The very great accuracy required in the data to compete with direct visual observations, however, makes the task of an auto-

matically recording spectrophotometer and an automatic calculator very difficult indeed.

May I close this paper with a plea that those who are interested in spectrophotometric measurements in color using industries do not expect too much from the use of a spectrophotometer. For example, the expert dyer, who knows both the fastness properties and the working properties of his dyes, can match shades, as it is called—or colors, if you are a physicist and object to the term "shade"—more quickly and satisfactorily by visual examination of his dyeings than he can with spectral reflection measurements. The expert can decide in a moment after looking at a dyeing what change to make in the formula. Also, by the use of north light, a daylight lamp and artificial light he can tell quickly if his dyeing matches the submitted sample of dyed goods under different kinds of illumination. Finally, it must be remembered that as a consequence of the fact that each dye has a characteristic reflection curve on a fabric as well as a characteristic absorption curve in solution, color matches can be made which match under different conditions of illumination only when the same dyes are employed for the match as for the original. The use of spectral reflection curves does not make it any more possible to get a match for the sample which will match under all conditions if identical dyes are not employed.

COLOR SPECIFICATION IN THE PULP AND PAPER INDUSTRY.*

By W. B. Van Arsdel

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Received March 21, 1931]

The pulp and paper industry has until very recent years been in the position of an industrial art, living by ancient traditions rather than by exact knowledge. Shortly before the opening of this century the application of chemical methods to the production of paper fibers from wood opened up a field of scientific development; some parts of the industry have been revolutionized, while others have undergone little or no

Table 1. *Spectral reflection of bleached wood-pulps.*

Wave length	Sample number									
	1	2	3	4	5	6	7	8	9	10
400	686*	630*	718*	635*	855*	590*	582*	793*	783*	658*
420	746*	710	750*	645*	870	630*	617*	828	812	712*
440	820	777	778	655	883	675	657	858	835	764
460	859	810	802	669	893	724	702	883	853	798
480	862	833	823	698	902	752	746	902	867	820
500	868	851	839	740	908	768	782	912	877	838
520	882	865	849	764	914	791	807	918	885	852
540	893	879	858	783	919	801	827	920	892	863
560	898	890	865	794	923	804	845	922	898	872
580	899	898	873	806	926	816	856	927	903	879
600	900	904	880	813	929	829	864	933	908	887
620	902	908	884	817	931	832	873	940	911	894
640	930	911	888	830	934	835	882	944	913	898
660	920	917	892	842	938	844	883	948	915	900
680	909	921	893	845	941	850	883	952	918	906
700	901	924	885	853	943	856	892	955	920	911

* Figures extrapolated.

change in the past century or more. It has been particularly difficult to introduce exact methods of testing and control of the product, partly, no doubt, because of the vagueness of many of the qualities we value in a sheet of paper. The control of color has been, and still is, in a highly unsatisfactory condition, but in this case not because the desired quality is vaguely defined, but rather for lack of an adequate method of meas-

* Presented at special session of the Optical Society of America on Industrial Color Standards, New York, February 26, 1931).

urement and specification. Color technologists have not clearly understood the requirements of this industry.

From the standpoint of manufacturer and user, pulps and papers are two distinctly different classes of material. The problem of color-specification is likely to be quite different in the two cases. One obvious general proposition, however, applies to both; colors of high saturation or chroma have only minor importance. A solution of the problem to be of real value must be satisfactory for colors that very nearly approach pure white. Next in importance are the tans and light browns. In one

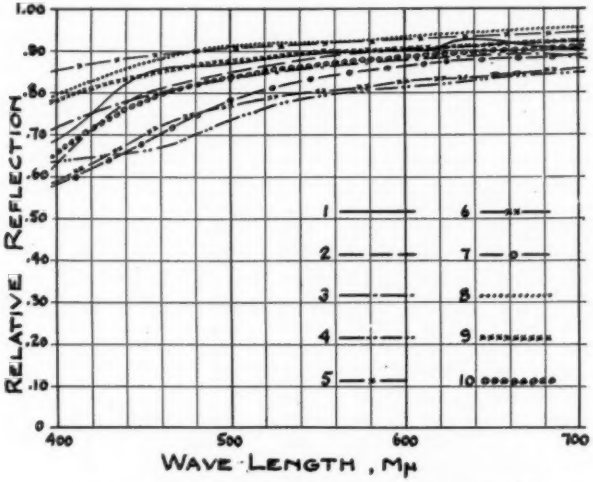

FIG. 1. *Diffuse spectral reflections of bleached wood-pulps.*

important respect specification of the color of a nearly white pulp is simpler than the general case; the hue is practically invariable. Table 1 gives the spectral reflection data, and Fig. 1 the corresponding spectral reflection curves† of ten different wood pulps, the range just about covering the upper and lower limits of bleached pulps. The curves all exhibit a gradual increase in absorption toward the violet end of the spectrum. These reflection factors have been transformed to monochromatic terms by a modification of the method described in the 1920–21 report of the Committee on Colorimetry, the modification consisting in the substitution of the 10000° black-body energy distribution

† Some of these curves were determined by the Bureau of Standards, others by the American Photoelectric Corporation, of New York.

for that of noon sunlight. This gives an approximation to the results which would be obtained with north-sky daylight, which is preferred over sunlight for matching the colors of pulp. The results are given in

TABLE 2. *Monochromatic analyses of bleached wood-pulps.*

Sample no.	Arbitrary color-number	Brightness	Purity	Dominant wave length
1	104.5	0.892	0.104	576
2	100	0.882	0.130	577
3	102	0.861	0.095	578
4	94	0.784	0.158	579
5	109	0.920	0.042	576
6	98	0.802	0.151	577
7	94	0.830	0.198	577
8	107	0.922	0.070	576
9	105	0.894	0.067	578
10	100	0.866	0.122	578

Table 2, and also graphically in Fig. 2, representing a small area near the center of the color-triangle. It is at once apparent that even the

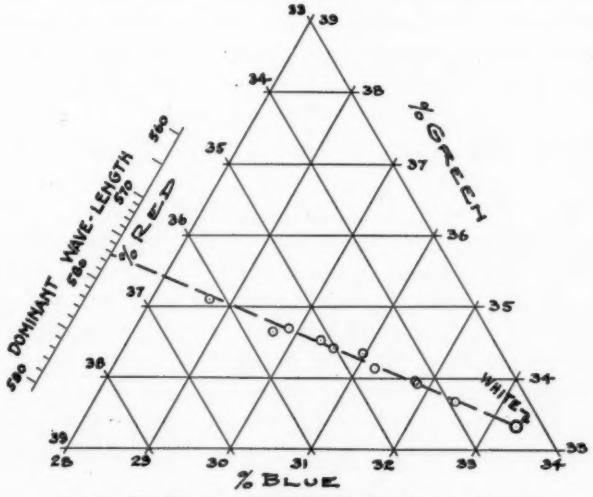

FIG. 2. *Coordinates of bleached wood-pulps in color triangle.*

yellowest sample lies very close to the white-point, and that all of the results fall approximately on the straight line representing the dominant wave length of 577 mμ. There is some evidence that the deepening in

color which is a result of aging a sample is accompanied by only a slight reddening of the hue.

It is obvious that the papermaker cannot produce a product which will be any whiter than the pulp he starts with, unless he bleaches the stock further—an expedient which is likely to be fatal to the other qualities of the paper. The pulp manufacturer and the papermaker are therefore both highly interested in the color of the pulp, and they are accustomed to judging chiefly the amount of yellow present, practically ignoring differences in total brilliance. There is a good reason for this custom, entirely apart from the fact that in the old standard grades of papermaking pulp high yellowness is quite likely to accompany a low brilliance. This reason is that a blue dye or pigment is added to the stock in the beater to neutralize the yellow tint, and the more of this constituent is used, the darker the finished paper will be.

Direct visual observation may be surprisingly accurate and reproducible in the hands of an experienced man. Apparently it is possible to train the color-memory so that one man can check his previous gradings very well from day to day; it is far more difficult, of course, to secure conformity of results between different observers. One device which is frequently employed to increase the precision of non-instrumental grading involves partly splitting a sheet of pulp, and spreading the two sides apart slightly so as to form a deep, narrow V; multiple reflection between the faces of the V intensifies the yellow constituent of the color so much that even the whitest pulps will show a pale straw-yellow color in the apex of the V.

The demand for reproducibility naturally led to attempts to prepare permanent material color standards, and in 1916 the Sulphite Pulp Committee of the Technical Association of the Pulp and Paper Industry proposed a system which in modified form has been fairly satisfactory.[1] Six flat disks, each about eight inches in diameter, were supported side by side in bearings in a long horizontal frame. A small motor rotated all of the disks simultaneously by means of a continuous belt. The recessed faces of the disks were filled with six different plaster mixtures made up by the formulas in Table 3 and numbered arbitrarily from 75 to 100.

Disks of pulp 3 1/2 inches in diameter were attached to the faces of the wheels so as to be whirled with them. The entire series of wheels was illuminated by a standard "daylight" lamp or battery of lamps. The

[1] *Testing Pulp for Color and Strength*, R. B. Wolf, *Paper*, *19*, No. 9, 11–19; Nov. 8, 1916.

pulp was then specified by the number of the wheel it most closely matched. There were several very valuable features in this machine; in the first place, the whole series was in the field of view at once, permitting deliberate re-check of the first judgment; secondly, the samples were fairly large and were brightly illuminated, thus achieving high sensitivity; and finally, the plaster color-standard could be scraped clean with a sharp tool whenever it became dirty. Surface inequalities of the sample were eliminated by the rotation. The operation of grading was very rapid, and permitted fairly good checks betweeen different observers. On the other hand, the soluble potassium chromate had a

Table 3.

No. of wheel	Water	Plaster of paris	Potassium chromate	Powdered magnesia
100	120	107	0	20
95	120	107	0.0245	20
90	120	214	0.1490	0
85	120	214	0.4660	0
80	120	214	0.6120	0
75	120	214	0.7770	0

tendency to accumulate at the surface during the setting of the plaster, so that when the surface was scraped off the resulting tint was lighter than it should have been. In addition, commercial plaster of paris was found to be far from constant in color. Work done in the Brown Company laboratories finally led to the following modification. Pure plaster of paris was prepared by precipitation and ignition under carefully controlled conditions; the resulting plaster was so white that no magnesia was needed, even for the highest-numbered wheels. The yellow color was secured by the use of precipitated zinc chromate, and this was applied as a definite sector of the wheel instead of being mixed with all of the plaster; a mixture of equal parts of the chromate and the plaster was found to give a sufficiently hard surface, almost as saturated in yellow as the pure chromate itself. The wheels were mounted on individual motors for quietness and convenience; all were set on a high table, level with the eyes of the observer, and a row of six ten-inch Macbeth Daylighting units above the observer's head gave high and uniform illumination. See Fig. 3. The arbitrary numerical scale was also changed somewhat; the pure white wheel, if one were used, would be No. 117, and the number decreases by three units for each seven-degree sector of yellow

introduced. From seven to eight wheels are commonly used, ranging in three-point steps from 93 to 111. Experienced color graders will check one another's results on sulphite pulps within two points, and any one man can usually check his own readings within one point.

The system just described operated well enough on bleached sulphite wood pulps, but when advances in manufacturing processes brought forth new types of highly purified wood fiber, partly originating from kraft instead of sulphite pulp, the color wheels were soon found to be inadequate. The wheels obviously present a single-variable system, brilliance and saturation not being independently variable. Some of the new pulps failed to match any of the wheels satisfactorily; in some cases,

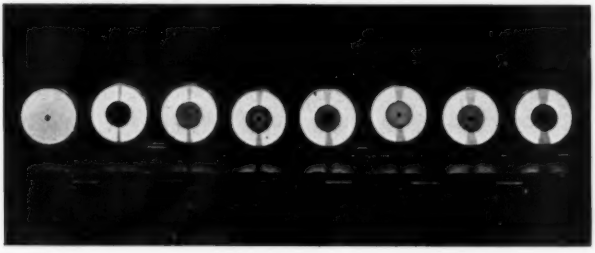

FIG. 3. *Sectored disks used for matching color of bleached pulp.*

for instance, the saturation of yellow was very low indeed, but the brilliance was so low that the pulp was distinctly gray. Different observers would differ in their grade for such a pulp by as much as five or six points. It is evidently necessary to allow independent variation of both saturation and brilliance if the specification is to be satisfactory. Of course if it is desired to use the same system for kraft and unbleached pulps, it is necessary also to extend the range of saturations to a much higher value, and that of brilliances to a much lower value, than was described above.

The zinc chromate used as a yellow pigment has not been entirely satisfactory, since it is subject to some change in color from the effects of the usual laboratory fumes of ammonia, sulphur dioxide and chlorine. Further experiments are now under way with a yellow ochre of easily reproducible source; this pigment appears to be much more stable, and has excellent tinting strength in the plaster mixture.

It will be of interest to examine the relation between the arbitrary color-number of white pulps and the colorimetric purity as calculated

from the reflection curves. Fig. 4 presents this relation graphically. While the correlation is not perfect, it is evident that the color grading on the wheels actually is a fairly good measure of the yellow saturation. The slope of the line indicates that a trained observer can just barely discriminate between two nearly white samples differing in purity by about 0.9%.

So far as we are aware, no one has yet devised a satisfactory set of material standards for white papers. In general, it would be very difficult to do so, except perhaps for a small number of standard brands

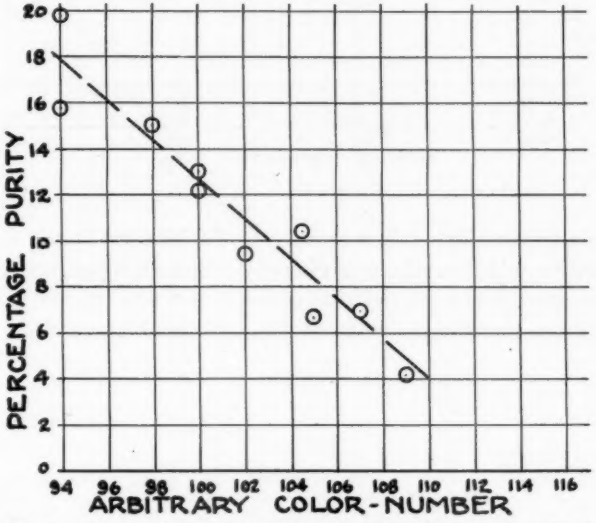

FIG. 4. *Relation between colorimetric purity and arbitrary color-number of bleached pulp.*

which it was desired to reproduce frequently. The first difficulty is that the hue may be anything, from red to violet, since a small amount of red dye is frequently used with the blue in the beater. In the second place, differences in translucency and surface finish would make it very difficult to attain really satisfactory color-matches. Table 4 and Fig. 5 present the spectral reflection curves* of three high-grade papers, one yellowish, one nearly neutral and the third bluish in hue. All of these samples were practically opaque and the surfaces were matte rather than glazed. There is evidently need for careful definition of what is meant by the

* Used by courtesy of the American Photoelectric Corp.

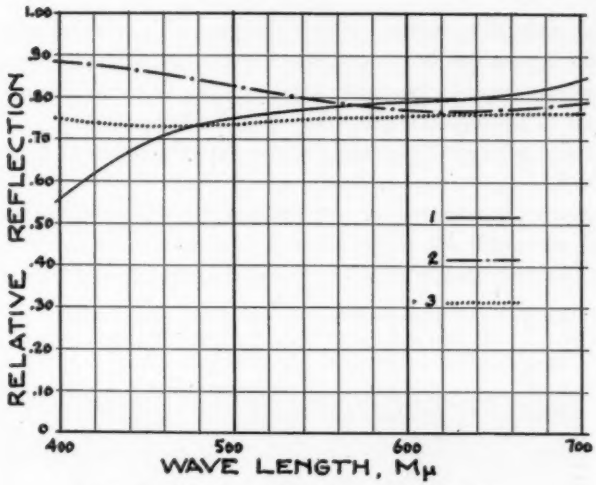

FIG. 5. *Diffuse spectral reflection of "white" papers.*

color of a paper, since only a fraction of the incident light—and sometimes only a small fraction—is diffusely reflected. Specification of the fractions specularly reflected, diffusely reflected and transmitted and of the spectral composition of each fraction would give the complete

TABLE 4. *Spectral reflection of "white" papers.*

Wave length	Sample number 1	2	3
400	558*	884*	745*
420	618	876	739
440	668	866	733
460	709	854	730
480	734	842	729
500	750	829	735
520	763	814	743
540	772	800	747
560	780	788	750
580	787	778	754
600	791	771	758
620	796	769	761
640	800	770	763
660	809	772	764
680	826	779	765
700	846	790	765

* Figures extrapolated.

story, but would probably fail to satisfy the papermaker. His manner of matching two samples of paper visually is to fold the sheets twice, so that four thicknesses are superimposed, and then, holding the samples side by side, tipping them this way and that, to look for differences in appearance which may show up at only one particular angle and not at others. Of course the color of a highly translucent paper such as glassine can be satisfactorily specified only by the inclusion of data on the transmitted light.

Actually, the paper industry has no means of specifying the color of its product except roughly by the use of such color-names as white, buff, cream, rose or dandelion. When a customer is more exacting, he is likely to submit a sample of paper and ask to have it matched. The papermaker will protect the sample from heat and light, but he realizes perfectly well that it is not a permanent standard.

The above considerations indicate that a method of colorimetry which would fully satisfy the requirements of the pulp and paper industry must fulfill the following conditions:

1. It must be at least as sensitive, particularly to differences in saturation, as the skilled human eye is under the conditions of best seeing.

2. Its standards must be reproducible at different times and in different laboratories.

3. It must be fairly rapid; to be really satisfactory for routine work, the final results should be available within a minute.

4. Allowance must be made for differences in the translucency and surface texture or finish of the samples.

5. While not absolutely essential, it is very highly desirable that the results should be expressed in the monochromatic terms of dominant wave length, purity and brightness.

In the light of these conditions many well-known colorimetric methods are seen to be unsuitable. Determination of diffuse spectral reflection, in the form of either a tabulation or a curve, fails to express the results in usable form; transformation to monochromatic terms is possible by a laborious arithmetical process, but the time required is impossibly long, and the precision is not all that it might be. The mechanical integrating device proposed[2] by A. C. Hardy would overcome the time difficulty, but it hard to believe that it would be sufficiently accurate. A method for specifying the color of butter was de-

[2] *A Recording Photoelectric Color Analyser.* J.O.S.A. *18*, 2, 116–117; Feb. 1929.

scribed in 1917 by Priest and Peters[3], involving determination of the reflection factor at only two wave lengths, 578 and 436 mμ; the lower the ratio of the second to the first, the yellower the sample. While the result is not identical with the colorimetric purity, it does correlate well with visually graded colors of bleached pulp; the most obvious objection is that a minor change in the shape of the reflection curve might alter the appearance of a sample without changing this ratio at the two chosen wave lengths. Most of the work on the colorimetry of paper has been done with some instrument utilizing the three-color principle—for instance, the Ives tint photometer, the Eastman colorimeter or the Pfund colorimeter. The latter introduced the important concept of specifying a color which closely approaches white only after intensifying its saturation by multiple reflection. Any three-color instrument, however valuable it may be in a laboratory investigation of, say, bleaching or color reversion, suffers from the very serious drawback that the results cannot be easily and certainly correlated with the appearance of the sample. Attempts have been made to develop a Maxwell disk with independently variable sectors of black and yellow, but the difficulties have so far been insurmountable. Of all the possibilities, the most promising seems to be the monochromatic colorimeter as described by Nutting[4] and by Priest,[5] but there is no evidence to show whether the requirements of reproducibility, precision and speed can be met. The definition and attainment of a standard white light-source is also one of the troublesome problems. It is possible that the very considerable expense of such an instrument can be materially reduced by eliminating the spectroscope and using instead one or more glass or liquid color-filters. The sensitivity might well be increased by arranging for multiple reflection from the face of the sample; in fact, Pfund pointed out[6] that this type of instrument lends itself admirably to monochromatic colorimetry; but it should first be determined whether the intensification factor can be made independent of differences in surface gloss and roughness. Is it probable that the sensitivity could also be increased by the use of a high level of illumination and wide-angle field.

Even if the physical data determining the color of a sample of pulp are precisely enough measured, however, the color technologist needs certain other data on color-vision to complete the specification. For

[3] Bur. Stds. Technologic Paper No. 92; June 30, 1917.
[4] Bull. Bur. Stds. *9*, 1–5, 1913. (Reprint No. 187.)
[5] J.O.S.A. *8*, 173–200; Jan. 1924.
[6] Proc. Am. Soc. Test. Mat. *20*, II, 441; 1920.

instance, the scale of pulp colors should correspond to equal steps of saturation, but the relationship between colorimetric purity and saturation has been determined for only a few individuals under a few of the many possible conditions. Again, the physical and psychological factors underlying the use of "blueing," in the laundry as well as in the paper mill, need to be better understood. The papermaker says he adds blue "to brighten up the stock," although obviously he is darkening it; he generally brings his paper well over onto the blue side, thus darkening it more than would seem to be necessary. For this purpose he may use a blue pigment or a blue dye, or both, and since the dye is likely to give a greenish tinge by subtractive color mixing, a little red dye is often added too. The red is used, like the blue, "to brighten up the color a little more." The psychology of this practice should be investigated. Since the final criterion of the color of paper can evidently be nothing but its brilliance, or physically its brightness, it should be possible to translate the two variables determined on the original pulp—percentage purity and percentage brightness—into a single composite figure representing the highest brightness of a neutral gray paper which can be made from that pulp. Such a figure would be the best possible specification, and a sufficient specification, for the color of a paper-making pulp.

DICTIONARY OF COLOR*

By M. Rea Paul

[National Lead Company Research Laboratories, Brooklyn, New York.
Received March 21, 1931]

The Dictionary of Color is primarily intended as a reference for the individual who seeks to relate colors with the names by which they are commonly identified. Just as the English Dictionary records words and their meanings according to their accepted usage, in the same manner this Dictionary of Color is a record of color words and the particular color sensations they identify, as established by consensus of opinion of existing works.

The ideal has been to present, in an especially usable form, a complete range of colors, with small step differences, and refer thereto a complete list of color names. The work is intended to serve as a reference source for all the recorded color names that have come into use in the English language, together with samples of the colors, so presented as to provide an acceptable standard.

On looking back through the years, it will be found that there exists no authority to which one may turn for an unqualified answer on what particular color sensation should be used to represent a color name. A person may select one of a number of books or color cards and accept it fully as his standard, but he will find that his neighbor has selected one of the others, and as no two exactly agree, their users cannot agree. A third may reject both, and set up his own idea as standard. The cause of this disagreement is primarily the lack of anything in a color name as such, that points unerringly to one single color sensation. The name "lemon yellow" would seem sufficiently accurate as a descriptive term, yet the color of lemons varies, and the memory for exact color sensations, when the original is not at hand, is often faulty. A further complication enters in the perfectly natural belief that one's own idea is correct, and the inclination is always present to adhere closely to one's own opinion. Out of these conflicting ideas, this Dictionary has grown, based upon an intensive study of thousands of named color samples obtained from every available source, and includes, so far as the writer knows, every work of any moment on this particular phase of the subject of color. The collecting of these samples, in practically every type of material, has covered a period of several years, and the comparing

* Presented at special session of the Optical Society of America, on Industrial Color Standards, New York, February 26, 1931.

and classifying of the color samples and color names has been carefully and painstakingly carried out. In the case of a single color name appearing in numerous books and on hundreds of color cards, it was necessary to let the opinion of the majority establish the actual name for that color. This reflection of popular usage has been maintained throughout the preparation of the entire Dictionary. It was not the intention in this work to introduce any new type of color system, or to offer color names that had not already appeared in print. In arriving at the particular color to be used to represent a color name, it was necessary to take the average from general practice. Establishing in this manner, consensus of opinion drawn from sufficiently wide sources, offers the only possible authority by which an acceptable standard may be had. If, in some persons' minds, the particular color selected by this method varies from their own ideas, the majority will find it in agreement. In no case can such variation be as great as exists between the wider extremes of variant usage, and in most cases it will be quite small.

Since any fairly complete method presenting colors for recording or matching must necessarily contain a large number of color samples, their arrangement, to be practical and usable, is of considerable importance. It is obviously impossible to show every variation of color with minute step differences. In the Dictionary, a little over 7,000 color samples are given. After extensive tests the writer considers even the most saturated of these colors to be reasonably permanent. The number of colors just mentioned was decided upon after practical tests as representing the limit for useful work. Even so, a casual inspection of the plates may give the impression that any two chosen color samples are alike. A trial at exact matching, however, will show that there is a distinct difference. These samples are divided into seven main groups—red to orange, orange to yellow, yellow to green, green to blue-green, blue-green to blue, blue to red, and purple to red. In each of these groups, all the colors that intervene between the stated terminals are found on single color plates. Each group is given eight successive plates —the first color plate quite saturated, and the seven following plates ever increasing in amounts of gray until the colors approach black. The plates are divided into twelve rows and twelve columns, representing the colors in twelve degrees with intermixtures, from full saturation at one end to a complete absence of hue at the other. The names by which the colors are identified are given on the left-hand pages, in spaces corresponding to the color samples. The names appearing are of current usage, all obsolete names and infrequently used synonymous names be-

ing given only in the Index. Here the aim has been to provide a complete list of all color names that have attained record in the English language, including all foreign names that have gained currency in English. Over 3,400 are given in the Index, and beside each is a date indicating the year in which that color name was first used in the English language. In no instance have names for colors been originated in this work. In addition to the Index, a large section of the Dictionary is devoted to detailed color notes, a History of Color Standardization, Textile names, Traditional names, Scientific names, terms found in literature, Principal color names showing frequency of use, etc.

On examining these various color names appearing in the Dictionary of Color, one cannot but be impressed with their utter lack of color descriptive value. Vague as most of these names are generally admitted to be, it is nevertheless believed that if the colors they identify can be established with a fair degree of accuracy, and future reference to those color names be restricted to those individual colors, then much will have been accomplished toward clearing up the misuse of the present terminology.

In addition, it is to be hoped that when the time arrives for new names to be invented or adopted, the individuals undertaking that particular task first study the miscellaneous assortment of unfortunate terms that comprise our present nomenclature, and be properly guided in their new selection, in order that future terms reflect, at least to some extent, the characteristics of the particular color the new name is to represent.

THE UNIT OF PHOTOGRAPHIC INTENSITY

The Present Status of Its International Standardization

By Loyd A. Jones

[Eastman Kodak Company, Rochester, N. Y. Rec'd. Mar. 26, 1931]

The Optical Society of America for several years has been interested in the efforts of the International Congress of Photography to establish and standardize a unit of photographic intensity. Some time prior to the Sixth International Congress of Photography which was held in Paris, July, 1925, a committee[1] was appointed by the president of the Optical Society of America to consider this subject and to prepare a report containing definite proposals for submission to the Sixth International Congress of Photography. This committee after due consideration of the problem prepared a report[2] which was presented at the February, 1925, meeting of the Optical Society. Later this report was submitted to the 6th International Congress of Photography held in Paris, July, 1925.[3] At this time the committee recommended that the unit of photographic intensity be defined as one visual candle of radiation having a spectral composition, in the region between 350 mμ and 700 mμ, identical to that emitted by a complete radiator (black body) at a temperature of 5000°K. Means of realizing this for practical purposes were suggested. Data were submitted in this report emphasizing the desirability of specifying a quality of radiation of relatively high color temperature (approximating sunlight quality). The 6th International Congress of Photography did not accept this recommendation. One of the chief reasons for the rejection of the committee's proposal was a very strong feeling on the part of certain members of the Congress that it was preferable to define the unit in terms of radiation of much lower temperature (2360°K), one that could be directly realized in the laboratory by a source of light suitable for use as a standard of intensity. Another reason contributing largely to its rejection was the lack of a method of sufficient generality and precision for the realization of the specified quality in the laboratory. The 6th International Congress of Photography therefore made the following recommendations:

[1] E. C. Crittenden, Raymond Davis, K. S. Gibson, A. C. Hardy, C. E. K. Mees, F. F. Renwick, A. G. Worthing, and L. A. Jones, Chairman.

[2] J.O.S. A. & R.S.I. *12*, 567; 1926.

[3] VIe Congrès International de Photographic, Société Française de Photographie, Paris, (1926), p. 60.

"1st. It is recommended to use, for sensitometric work, a light source of which the radiation is identical with that of a black body at 2360° (absolute).

"The intensity of this source shall be expressed in candles; this intensity shall be measured visually by ordinary photometric procedure in comparison with the usual photometric standards.

"2nd. In case it is considered necessary to use radiation representing approximately the radiation of a black body at 5000° absolute (average daylight day) there shall be placed before the light source provided in the preceding paragraph, a colored filter suitably chosen."

The Congress further provisionally recommended that a filter composed of two solutions (copper sulphate and copper ammoniacal sulphate) should be used with the 2360° source as a means of obtaining, for practical purposes, radiation of 5000° quality. This Congress, therefore, in effect recommended two standards for the unit of photographic intensity. Obviously this is undesirable and does not constitute a solution of the problem.

Some time prior to the 7th International Congress of Photography, which was held in London, July, 1928, the Optical Society's committee[4] again took up the consideration of the problem. No satisfactory means had been found for realizing in the laboratory a standard of intensity emitting radiation *identical* to that of a black body at 5000°K. Two members of this committee, Messrs. Davis and Gibson, had, however, done an extensive piece of work[5] on the construction of a filter which, when combined with a "gray body" radiatior operating at a color temperature of 2360°K, made available radiation *practically* identical with that of mean noon sunlight as defined by data supplied by Dr. C. G. Abbot of the Smithsonian Institution. After a rather lengthy discussion of the subject, the majority of the committee considered it advisable to propose mean noon sunlight as the *quality* of radiation in terms of which to define the unit of photographic intensity. A report was therefore prepared and submitted to the 7th International Congress and this report was published in the Proceedings of that Congress.[6] The essential recom-

[4] E. C. Crittenden, Raymond Davis, K. S. Gibson, A. C. Hardy, H. E. Ives, C. E. K. Mees, A. G. Worthing, and L. A. Jones, Chairman.

[5] Proceedings of the Seventh International Congress of Photography, W. Heffer & Sons Limited, Cambridge, (1929), p. 161. The complete paper by Davis and Gibson has now been published as Bur. Stand. Misc. Pub. No. 114, Jan., 1931.

[6] Ibid. p. 152.

mendations as made in this report to the 7th International Congress of Photography are as follows:

"1. It is recommended that the unit of photographic intensity be defined as one visual candle power of mean noon sunlight.

"2. It is recommended, in the determination of speed, that the illumination incident on the photographic material shall be not less than 1.0 meter candle.

"3. It is recommended that the exposure be nonintermittent and that the variation in exposure be produced by a variation of the time factor of exposure.

RECOMMENDATIONS FOR REALIZATION OF THE SPECIFIED SPECTRAL COMPOSITION

"1. It is recommended that the following relative energy values (derived from data by Dr. C. G. Abbot of the Smithsonian Institution) be adopted as defining the spectral composition of mean noon sunlight:

(mμ)	Relative energy	(mμ)	Relative energy
350	—	550	101.7
60	16.0	60	100.0
70	20.5	70	98.4
80	25.1	80	97.2
90	30.1	90	95.6
400	45.2	600	95.2
10	57.3	10	94.3
20	65.8	20	93.2
30	69.2	30	92.2
40	77.8	40	91.0
450	86.8	650	89.7
60	92.2	60	88.5
70	96.9	70	86.4
80	99.0	80	84.7
90	100.6	90	82.7
500	101.8	700	80.5
10	101.2	10	78.1
20	101.2	20	76.1
30	101.1	—	—
40	100.9	—	—

"2. It is recommended that for practical purposes the realization of the specified spectral composition be accomplished by using a source which emits radiation having a spectral composition approximately identical with that emitted by a complete radiator (black body) at a temperature of 2360°K together with a selectively absorbing filter.

"3. As satisfactory for use as the source of such radiation are recommended: (a) A cylindrical acetylene flame emitting radiation of color temperature 2360°K. (b) An incandescent electric lamp operated so as to emit radiation of color temperature 2360°K.

"4. It is recommended that the selectively absorbing filter be made by using two solutions compounded according to the following formula, the complete filter to consist of a one-cm layer of each solution contained in a double cell made by using three plates of borosilicate crown glass (refractive index, D line = 1.51), each 2.5 mm thick:

Solution A

Copper sulphate ($CuSO_4 \cdot 5H_2O$)	3.707	gm
Mannite ($C_6H_8(OH)_6$)	3.707	gm
Pyridine (C_5H_5N)	30.0	cc
Water (distilled) to make	1000	cc

Solution B

Cobalt ammonium sulphate ($CoSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$)	26.827	gm
Copper sulphate ($CuSO_4 \cdot 5H_2O$)	27.180	gm
Sulphuric acid (Sp. gr. 1.835)	10.0	cc
Water (distilled) to make	1000	cc

The light transmission of this filter for the radiation emitted by a complete radiator at a temperature of 2360°K is 0.1352. This is the factor by which the candle power of the source must be multiplied to obtain the candle power of the source-filter combination. Since the radiation from an acetylene flame operating at color temperature 2360°K, or the radiation from an incandescent electric lamp operating at color temperature 2360°K, is practically identical in spectral composition with that of a complete radiator operating at a temperature of 2360°K, this factor applies also to radiation from these sources."

This report and others presented by various national committees of the Congress were discussed and a resolution defining the international unit of photographic intensity was passed. The official text of this resolution is as follows:[7]

[7] Ibid. p. 173.

"This meeting of the 7th International Congress recommends to the National Committees that the photographic unit of intensity for the sensitometry of negative materials shall be defined as the intensity of a filtered source of radiation having a luminous intensity of one international candle, and produced by a gray body at a colour temperature of 2360°K, together with a selectively absorbing filter made up as follows:—Two solutions compounded according to the following formula, the complete filter to consist of a one-cm* layer of each solution contained in a double cell made by using three pieces of borosilicate crown glass (refractive index, D = 1.51), each 2.5 mm thick.

Solution A

Copper sulphate ($CuSO_4 \cdot 5H_2O$)	3.707	gm**
Mannite ($C_6H_8(OH)_6$)	3.707	gm**
Pyridine (C_5H_5N)	30.0	cc
Water (distilled) to make	1000	cc

Solution B

Cobalt ammonium sulphate ($CoSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$)	26.827	gm**
Copper sulphate ($CuSO_4 \cdot 5H_2O$)	27.180	gm**
Sulphuric acid (Sp. gr. 1.835)	10.0	cc
Water (distilled) to make	1000	cc

* Tolerance in thickness shall be ± 0.05 mm.

** For practical purposes an accuracy to the second place of decimals is probably sufficient.

"It is recommended that the foregoing resolution shall come into force as a decision of this 7th International Congress if and when ratified by the National Committees represented at this Congress."

It will be observed that the Congress did not accept the Optical Society committee's recommendation for defining the unit of photographic intensity in terms of mean noon sunlight. It did, however, adopt a source-filter combination identical with that recommended by this committee as a practical means of realizing the standard proposed by this committee.

It should be noted that the resolution passed by the 7th International Congress of Photography comes into force as a decision of that congress only "if and when ratified by the National Committees represented at this Congress." It seemed desirable, therefore, that the Optical Society of America should take some definite action in recommending to the

United States National Committee of the International Congress of Photography the acceptance or rejection of the resolution passed by the 7th International Congress of Photography. The Committee of the Optical Society[5] therefore prepared a report which was presented at a meeting of the Optical Society of America in New York City, February, 1929, in which it made a definite recommendation that the Society recommend the ratification of this resolution by the United States National Committee.

The Executive Council of the Optical Society of America at a meeting held in New York City, February, 1929, acting in behalf of the Optical Society passed the following resolution:

"Moved that the Secretary of the Optical Society be instructed to notify the Secretary of the National Committee of the International Congress of Photography that the Optical Society of America recommends that the American National Committee ratify the recommendation of the Seventh International Congress of Photography (held in London, July, 1928) relating to the international unit of photographic intensity which reads as follows:

"'This meeting of the 7th International Congress recommends to the National Committees that the photographic unit of intensity for the sensitometry of negative materials shall be defined as the intensity of a source of radiation having a luminous intensity of one international candle, and produced by a gray body at a colour temperature of 2360°K, together with a selectively absorbing filter made up as follows:—Two solutions compounded according to the following formula, the complete filter to consist of a one-cm* layer of each solution contained in a double cell made by using three pieces of borosilicate crown glass (refractive index, D = 1.51), each 2.5 mm thick.

Solution A

Copper sulphate ($CuSO_4 \cdot 5H_2O$)	3.707	gm**
Mannite ($C_6H_8(OH)_6$)	3.707	gm**
Pyridine (C_5H_5N)	30.0	cc
Water (distilled) to make	1000	cc

Solution B

Cobalt ammonium sulphate ($CoSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$)	26.827	gm**
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Sulphuric acid (Sp. gr. 1.835)	10.0	cc
Water (distilled) to make	1000	cc

* Tolerance in thickness shall be ± 0.05 mm.

** For practical purposes an accuracy to the second place of decimals is probably sufficient.

"'It is recommended that the foregoing resolution shall come into force as a decision of this 7th International Congress if and when ratified by the National Committees represented at this Congress.'

"In ratifying this proposal the Optical Society of America understands that the intent of this recommendation is as follows:

"(1) The intention is to specify two things, (a) the *unit* in which the intensities of light sources are to be expressed, and (b) the *quality* of light to be used.

"(2) The *unit* is to be the International Candle, implying further that the intensities measured and stated will be luminous intensities as in visual photometry.

"(3) The *quality* of light to be used for sensitometry of negative materials is to be that which results from passing the radiation from a gray body at 2360°K normally through the filter described.

"(4) The gray body and the selectively absorbing filter together shall be considered as the effective source in specifying the intensity (candle-power).

"(5) The procedure recommended for determining the intensity of the combined effective source is to multiply the intensity of the primary source (gray body) by the appropriate transmission factor of the filter which is 0.135. This factor has been computed from the spectral transmission of the filter via the relative energy distribution of 2360°K and the relative visibility function adopted by the sixth session of the International Commission on Illumination at Geneva, 1924.

"(6) This resolution does not state or imply the value of illumination to be used at the test plane during the sensitometric exposure, nor does it place any limitations on the intensity of the light source to be used."

The secretary of the United States National Committee of the 7th International Congress, Dr. C. E. K. Mees, was therefore in due course notified by the secretary of the Optical Society of America as to this action. The secretary of the United States National Committee then

forwarded this notification to the secretary of the International Congress on Photography, thus giving the necessary ratification to the resolution passed by the 7th International Congress in so far as the United States National Committee was concerned.

Complete information is not at hand as to the action of all of the other national committees represented at the 7th International Congress. It is known, however, that one of these national committees does not agree with the recommendations made by the 7th International Congress and therefore has withheld its ratification of the action of that Congress. The resolution of the 7th International Congress relative to the international unit of photographic intensity therefore has not come into force as a decision of that Congress and the matter must again be discussed at the 8th International Congress to be held in Dresden, August, 1931. At present a committee of the Optical Society of America[8] is giving the matter further consideration and is preparing a report for submission to the 8th International Congress.

[8] B. H. Carroll, E. C. Crittenden, Raymond Davis, A. C. Hardy, H. E. Ives, L. A. Jones, C. E. K. Mees, A. G. Worthing, and K. S. Gibson, Chairman.

THE INSTITUTE OF APPLIED OPTICS OF THE UNIVERSITY OF ROCHESTER

By T. R. Wilkins

[Rochester, New York. Received February 27, 1931]

At the meeting of the Optical Society in Ithaca a year ago, announcement was made by Dr. Rush Rhees, the president of the University of Rochester, of the founding of the Institute of Applied Optics at that University. Excellent progress has been made in the organization of the Institute. With the removal of the College for Men to its spacious new campus, the Institute of Applied Optics has moved into its home in the John J. Bausch-Henry Lomb Memorial Building which it is to share with the physics department of the University. It is proposed in this article to outline the type of training which the Institute will give, and to tell something of its organization and of the facilities which have been provided.

Associated with the University in this enterprise are the Bausch and Lomb Optical Company and the Eastman Kodak Company. These two great Rochester industries are cooperating not only in financing the project but in making available some of their equipment and certain services by members of their scientific staffs. The administration of the Institute is in the hands of a committee composed of Dr. Rhees, Dr. T. R. Wilkins (acting director), Mr. L. A. Jones of the Eastman Kodak Company and Mr. W. B. Rayton of the Bausch and Lomb Company.

In announcing the project a year ago, Dr. Rhees pointed out that the training to be given was of a scope and type not at present duplicated elsewhere in this country. The Institute is planned, as shown in the accompanying chart, for three main groups of students—those interested in the industrial applications of optics, those in the design and construction of optical instruments, and those preparing for licensure in optometry. For all three groups, four-year courses leading to the B.Sc. degree have been provided. The entrance requirements are identical with those required by the University in other courses.

The subjects in the three courses are listed below.

Group A. Industrial Applications of Optics

Freshman Year

Rhetoric
Mathematics
General Physics

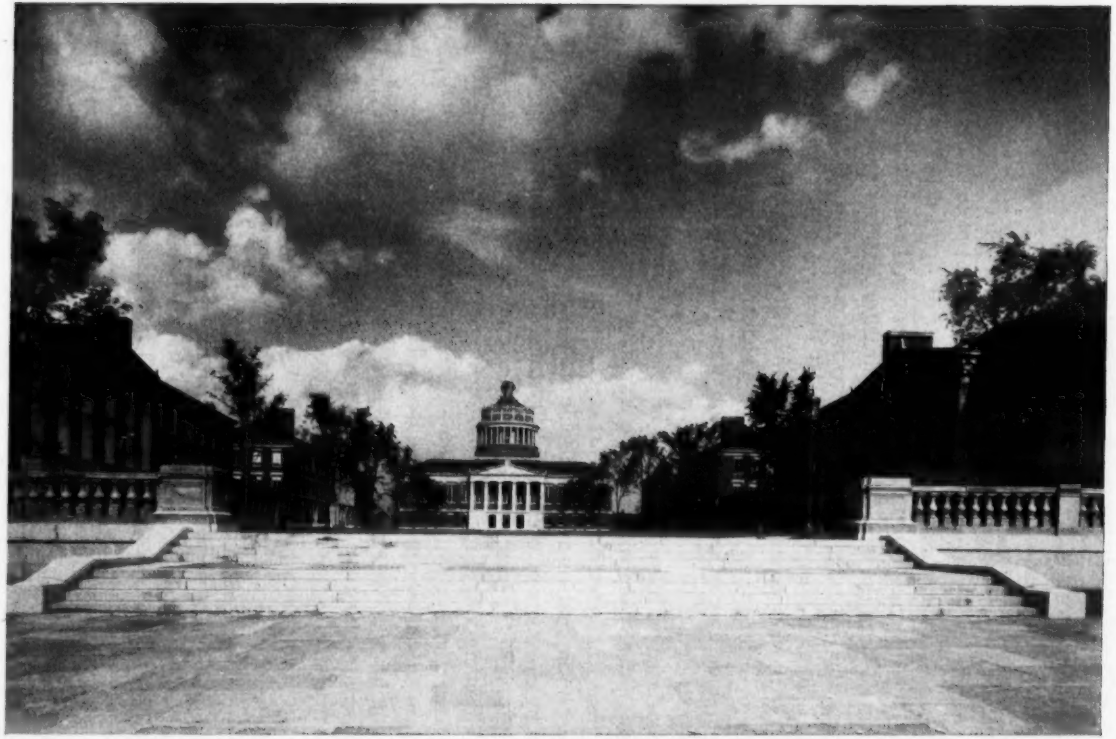

FIG. 1. *View of the main quadrangle of the University of Rochester. The John J. Bausch-Henry Lomb Memorial Laboratory is in the far right hand corner of the quadrangle.*

Chemistry
Physical Education

Sophomore Year

German or French
Mathematics (Analytical Geometry and Calculus)
Physical Measurements
Psychology
Drawing
Machine Shop and Optical Shop

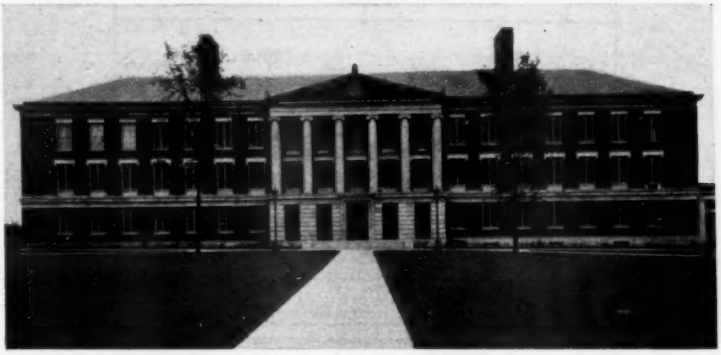

FIG. 2. *The John J. Bausch-Henry Lomb Memorial Laboratory.*

Junior Year

German or French
Physiological Optics
Geometrical Optics
Introductory Physical Optics (first semester)
Photography (first semester)
Applications of Physical Optics (second semester)
The Radiation Spectrum (second semester)
General Elective in a non-scientific subject.

Senior Year

As will be seen from the chart of the scheme of courses, Group A students begin to diverge slightly in the third year but the divergence becomes much more marked in the fourth year where a special effort has been made to provide training for two main groups.

1. Group A1: Industrial Applications of Optics—designed especially to train technicians who ought to be familiar with the use of the optical apparatus employed in the many branches of applied optics.
2. Group A2: The Design and Construction of Optical Instruments—arranged to make available a thorough practical training to those interested in becoming designers of optical apparatus. Because of the close relations between the Institute and the sponsoring companies, the opportunities and facilities available in this field are unusual.

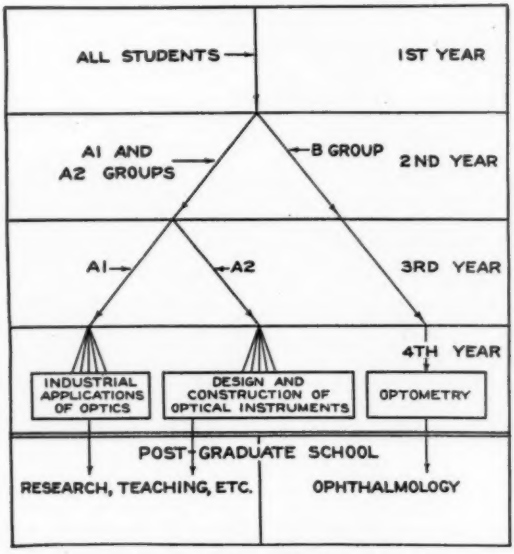

FIG. 3. *Diagram showing main lines of training in school of optics.*

Group A1. Industrial Applications of Optics

No specific courses have been laid down for the senior year. Students will arrange their work in consultation with the professors. A list of courses which will be offered is given below,

For the benefit of students desiring to take up specific branches of applied optics, the following suggestions are made to assist them in their elections.

1. For industrial applications of optics.
   Advanced Photography

Advanced Physical Optics
Visual Sensitometry and Colorimetry
Electricity
Spectrophotometry and Radiometry
Polarimetry
Applied Spectroscopy and Interferometry

Group A2. Design and Construction of Optical Instruments

The time of students in this course will be largely assigned to:

The design of lens systems
The testing of optical systems
The mechanical design of optical instruments

The distribution of time among these courses will be a matter of arrangement at the time of registration and will depend on whether the student wishes to specialize in optical or mechanical design.

GROUP B. OPTOMETRY

Freshman Year

Rhetoric
Mathematics
General Physics
Chemistry
Physical Education

Sophomore Year

Geometrical Optics
Psychology
Biology
German or French
Optical Shop
Optometric Practice
Vertebrate Anatomy
Physiology 1
Physical Education

Junior Year

German or French
Physical Optics
Advanced Geometrical Optics
Optical Shop
Optometric Practice

Physiological Optics
Drawing
Anatomy of the Eye

Senior Year

Optometric Practice
Optometric Clinic
Pathology of the Eye
Electives

The program of the Institute is now in full operation. Appointments to its teaching staff have been made in Physiological Optics, Spectrophotometry and Radiometry; in Geometrical Optics; Physical Optics; Mechanical Design of Optical Instruments; Optometric Practice; Anatomy of the Eye; and in Optical Shop Work. All these departments and an instrument shop are equipped and at work. In addition, courses have been arranged and are being given by members of the scientific staffs of the sponsoring companies as will appear below.

PHYSIOLOGICAL OPTICS, SPECTROPHOTOMETRY AND RADIOMETRY

Work in these fields is under the direction of Dr. Brian O'Brien (PhD., Yale, 1922) who comes to the Institute from the J. N. Adam Memorial Hospital at Perrysburg where for the last seven years he has been mainly concerned with radiation measurements in the ultraviolet and the effects of light upon living organisms. The University is under debt to the city of Buffalo for the loan of the laboratory equipment which Dr. O'Brien had built up at the J. N. Adam Hospital. This has made it possible for the work in radiometry to start out without many of the delays which otherwise would have been incident to the equipping of a new laboratory.

Associated with Dr. O'Brien in the course in physiological optics is Dr. W. Berry, professor of psychology in the University who brings, in a series of lectures, the view point of the experimental psychologist, dealing expecially with such topics as after-images, space perception and other aspects of the psychology of vision.

In spite of the very considerable amount of careful work which has been done in physiological optics, there is a decided tendency to neglect the physiological aspects of many applications of optics. In an attempt to remedy this, and because of the importance of visual phenomena in the design and use of optical instruments of all kinds, every effort is

being made to correlate physiological optics with the other branches of optics dealt with in the Institute.

In addition to general physiological optics, more detailed quantitative consideration of certain divisions of the subject is given in courses on visual sensitometry and colorimentry, while the physical background is discussed under the headings of spectrophotometry and radiometry.

In view of the importance of light sources, both natural and artificial, the measurement and interpretation of spectral energy distribution

FIG. 4. *A corner of the radiometry laboratory.*

curves is treated at some length. The applications of emission and absorption spectra to quantitative and analytical methods are also included in the more purely physical considerations of spectrophotometry.

Some emphasis is being placed on measurements of the energy distribution in the solar ultraviolet spectrum, more particularly near the short wave-length limit. The relation of this to atmospheric ozone and solar activity, and the importance of certain photochemical effects of biological significance produced by radiations in this spectral region, make the subject of both physical and physiological interest.

The courses offered in this department are:

PHYSIOLOGICAL OPTICS

An introductory course on the physical, physiological and psychological aspects of vision. Accomodation, adaptation, characteristics of photopic and scotopic vision, color vision, binocular vision and space perception, are discussed after a preliminary consideration of the necessary anatomy and physiology.

FIG. 5. *A sector-disc and quartz spectrograph in the spectrophotometry laboratory.*

VISUAL SENSITOMETRY AND COLORIMETRY

Quantitative consideration of the eye as a physical instrument. Sensitivity of the eye to brightness differences, hue differences, saturation differences. Determination of the spectral sensitivity of the eye. Visual acuity, critical frequency, flicker phenomena, and their relation to wave length and intensity of stimuli. Colorimetric measurements and color calculations.

SPECTROPHOTOMETRY AND RADIOMETRY

Measurement of total radiation and energy distribution in the spectrum of light sources. Spectral transmission, reflection and scattering. Visual, thermal, photoelectric and photographic methods.

EQUIPMENT

The equipment consists of precision colorimeters of the monochromatic and trichromatic types, apparatus for the study of flicker phenomena and for visual sensitometric measurements. Complete spectroradiometric equipment is available for ultraviolet, visible and infrared measurements and a medium dispersion quartz spectrograph with special attachments for photographic spectrophotometry. Provision has been made for the mounting of a heliostat, pyrheliometer and a recording pyranometer, in connection with the study of ultraviolet solar radiation.

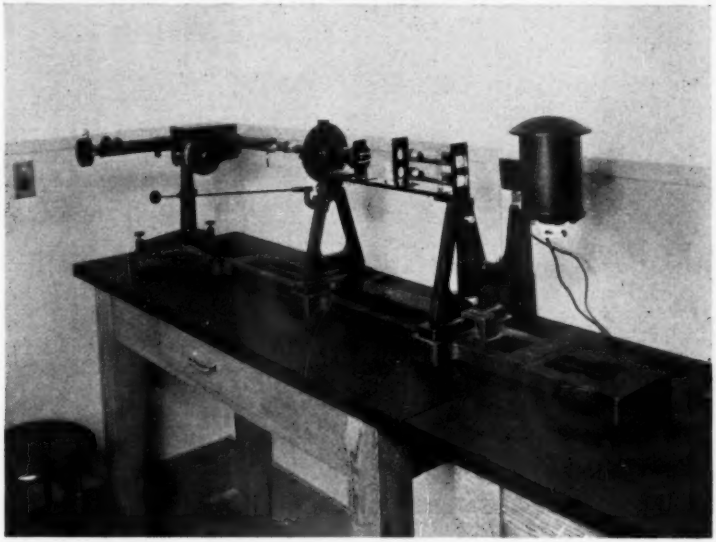

FIG. 6. *Universal spectrophotometric equipment.*

RESEARCH

In addition to the systematic study which is being made of ultraviolet solar radiation and atmospheric ozone, investigations are in progress on the horizontal transmission of the earth's atmosphere, on photographic methods in spectrophotometry and on energy distributions in the spectra of certain flames.

GEOMETRICAL OPTICS

Mr. Rudolf Kingslake, M.Sc., A.R.C.S., of the Imperial College of Science, London, was appointed a year ago as assistant professor of

geometrical optics. He brings to the Institute not only a thorough training, but industrial experience as an optical designer. During the past year equipment has been assembled for the regular courses announced in geometrical optics, and, in addition, work has been started on the design and construction of two complete lens-testing benches, one visual and the other photographic, suitable for research investigations.

FIG. 7. *Elementary geometrical optics laboratory.*

The principal courses in the field of Geometrical Optics are as follows:

ELEMENTARY COURSE

An elementary course for optometrists. In somewhat modified form, this course is being repeated in the evenings for the benefit of a number of men in the optical firms in the city who desire an elementary course on mirrors, lenses and prisms and their action.

INTERMEDIATE COURSE

This is a general survey of the whole subject of thin and thick lenses, mirrors, prisms, etc., with a detailed discussion of their principal applications in such optical instruments as telescopes, microscopes, spectrometers and spectrographs, refractometers, periscopes, rangefinders, coe-

lostats, sextants, etc. The course includes a discussion of depth of focus, field of view, apertures, stops and pupils, brightness of images, and the elementary properties of the Seidel and Chromatic aberrations.

LENS DESIGN

A course of lectures on the systematic methods of lens design developed by Professor A. E. Conrady, giving the student a thorough grounding in the fundamental properties of the aberrations and methods for their removal. The lectures are followed by a computing period in which actual lens systems will be designed by the students. The course includes the tracing of ordinary and skew rays, the thin-lens expressions for spherical and chromatic aberration; the analytical expressions for coma, astigmatism, petzval curvature and distortion, and the effects of stops on aberrations. The physical nature of light is also discussed and by its aid, tolerances are deduced for the various image defects so that manufacturing economies may be effected wherever possible. The design of simple and aplanatic telescopes, microscopes, eye-pieces, and simple photographic lenses is discussed in full, and at each stage in the work, emphasis is laid on the degree of precision necessary in the computations.

This course also is being given in the evenings for men in the sponsoring companies who are interested in the design of optical systems.

OPTICAL TESTING

This is a laboratory course on the testing of optical units and complete optical systems. It includes simple tests on surfaces, prisms and parallel plates, and tests for veins and strain. The common methods of lens testing, including star, Foucault and Hartmann tests are studied, and also the various applications of the Hilger Interferometer. Photographic lenses are tested both on the lens-testing bench and also by direct photography of suitable test objects.

EQUIPMENT

The laboratory equipment for this part of the work in the Institute includes:

Hilger lens and prism testing interferometer

Pulfrich refractometer

Zeiss Abbe refractometer

Watts spectrometer, reading to 5″ by two micrometer microscopes

Bausch and Lomb microscope, with scales for determining magnification, apertures, etc.

Bausch and Lomb 3-inch telescope

Prism autocollimator

Set of twelve telescope objectives, each with a different defect, for study purposes.

Bausch and Lomb two-coordinate measuring microscope.

Students' optical benches, fittings, spectrometers, comparators, etc.

RESEARCH

In addition to these regular courses, opportunities will be available for research into the design of special types of lenses, and on the correlation between aberrations calculated geometrically and actually realized physical images. New methods for measuring image-defects and for testing optical systems will also be developed.

FIG. 8. *A corner of the interferometer laboratory—showing the Hilger lens testing interferometer.*

PHYSICAL OPTICS

Dr. A. M. Taylor has direction of this division. He comes to the Institute from the Cambridge University where he was for two years holder of the William Ramsay Memorial Research Fellowship. Dr Taylor is author jointly with F. I. G. Rawlins of *The Infrared Analysis of Molecular Structure.*

The courses offered in physical optics are:

INTRODUCTORY

An elementary course in which the chief phenomena of interference, diffraction, and polarization are studied.

PHYSICAL OPTICS APPLIED TO INSTRUMENTS

A course designed to cover the construction and use of the various optical devices employed in instrument design. The uses of polarizing

FIG. 9. *Large electromagnet and other apparatus in the physical optics laboratory.*

prisms of various types, compensators, quartz wedges, etc. are studied. The optical designs of such instruments as spectrometers, polarimeters and spectrophotometers, petrographic and spectrographic microscopes, spectroheliographs etc. are examined in detail.

ADVANCED PHYSICAL OPTICS

The physical theory of light is here developed in a series of mathematical lectures accompanied by a related laboratory course. The phenomena of diffraction and interference are dealt with in detail as results of a wave theory. Then the electromagnetic theory is developed and its

consequences deduced; particularly the phenomena of surface reflection, refraction and the production of elliptically polarized light, at absorption, metallic reflection and dispersion. The emission of light on the classical quantum theory, the radiation laws, scattering, dispersion, the Raman effect, fluorescence and the photoelectric effect are also among the topics dealt with.

There are two more specialized courses.

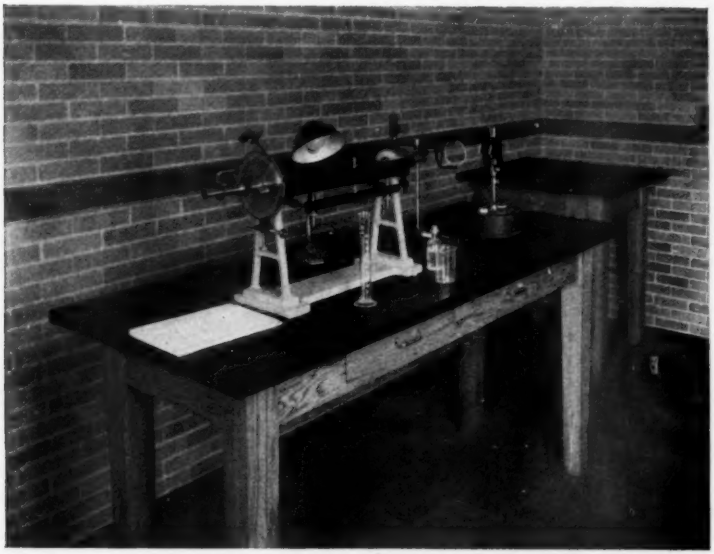

FIG. 10. *A typical standard polarimeter.*

POLARIZED LIGHT AND ITS APPLICATIONS

This is concerned with the theory and production of polarized light and especially with its applications in instrument design. It treats, therefore, in detail, photometers, polarimeters, saccharimeters and petrographic microscopes. Magneto-optics, electro-optics and photoelastic effects are also studied.

APPLIED SPECTROSCOPY AND INTERFEROMETRY

Covers both the qualitative and quantitative methods of chemical analysis by spectroscopic methods, the application of ultraviolet and infrared spectroscopy to industrial measurements; the design and use of spectrographic instruments; the mounting of gratings; resolving power

of the instruments and of the phototraphic plate; use of interference spectroscopes and the industrial applications of interferometers.

EQUIPMENT

The apparatus available for the ordinary courses includes:
Adam Hilger and Bausch and Lomb spectrometers and cameras
Bausch and Lomb Martens spectrophotometer
Bausch and Lomb monochromator and camera

FIG. 11. *The physics-optics instrument shop.*

Adam Hilger interferometers of the Michelson and Fabry-Perot type, Jamin interferometer and gas refractometer
Adam Hilger polarimeter
Leitz polariscope
Pye electromagnet capable of producing fields of 50,000 gauss
Optical benches, diffraction apparatus, microscopes, comparators etc.
Transformers, induction coils, discharge tubes, vapor lamps, etc.

RESEARCH

The chief field for research will be that of spectroscopy and allied subjects, particularly in the ultraviolet region. A five-meter grating vacuum

spectrograph of large apperture is under construction, which when it is in use will open up a large field of new work, especially in connection with the absorption spectra of gases in the far ultraviolet. The instrument has a system of air-locks whereby the time required for the whole operation of exposing a plate will be much reduced, facilitating work in that respect. The best range of the instrument will be from 3000A to 300A and it will be one of the largest and most powerful instruments yet built.

MECHANICAL DESIGN OF OPTICAL INSTRUMENTS

With the appointment of Mr. Gustave Fassin, until recently designer to the Societe d'Optique Belge and for some years instructor in the technical school of Ghent, Belgium, there is assured a real contribution to the work in mechanical design being done in this country. Mr. Fassin, while in Belgium, designed considerable research apparatus for some of the larger American universities and the range of his experience in design is well-known abroad.

The Institute has been extremely fortunate, too, in having Mr. Henry F. Kurtz of the Bausch and Lomb Company give general superintendence to the development of this phase of its program. At present a course is being given which covers not only the fundamentals of design but takes into account factory practice as related to production costs. Those readers who may be interested further in what is being attempted in this work will find its content discussed in some detail in the bulletin of the Institute to which reference is made below.

PHOTOGRAPHY

The fact that the Eastman Kodak Company is one of the two companies sponsoring the work of the institute naturally suggests that the work in photography would be unusual. Dr. C. E. Kenneth Mees, director of research of the Eastman Kodak Company, has taken personal supervision of this instruction and has arranged a notable series of lectures by various members of his research staff, during the present year. A laboratory course accompanies the lectures. The topics and the lecturers are as follows:

"The Science of Photography," Dr. C. E. K. Mees; "The Characteristic Curve of Photographic Materials and Its Properties," Dr. C. E. K. Mees; "Photographic Materials, their Preparation and their Properties," Dr. C. E. K. Mees; "The Physical Chemistry of the Light Sensitive Layer," Dr. K. C. D. Hickman; "Exposure and the Latent Image," Dr.

E. P. Wightman; "The Chemistry of Development," Dr. E. P. Wightman; "The Chemistry of the After-processes," Mr. J. I. Crabtree; "Sensitometry," Mr. L. A. Jones; "Sensitometry, Including Color Sensitiveness and Sensitiveness of Papers," Mr. L. A. Jones; "The Theory of Tone Reproduction," Mr. L. A. Jones; "Contrast in Papers and the Theory of Printing," Mr. L. A. Jones; "Sharpness, Resolving Power, and Graininess," Mr. L. A. Jones; "Color Sensitivity and Light Filters,"

FIG. 12. *A typical problem in the mechanical design laboratory.*

Dr. C. E. K. Mees; "Orthochromatic and Color Contrast Photography," Dr. C. E. K. Mees; "Photographic Photometry," Mr. L. A. Jones.

OPTOMETRIC PRACTICE

In 1923, the legislature of the state of New York enacted an amendment to the optometry law which provides that after January 1, nineteen hundred and thirty any person who desires to enter the profession of optometry must have been graduated from a recognized university with the degree, bachelor of arts or bachelor of science, and a certificate of graduation in optometry. It was apparent that with the facilities in geometrical, physiological and physical optics in the institute of applied optics which was then in contemplation at the University, it would be

FIG. 13. *One of the five clinic rooms in the optometric section.*

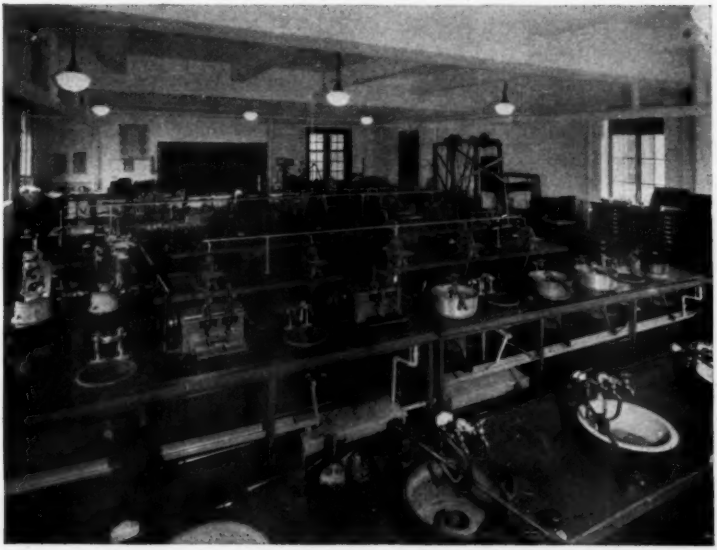

FIG. 14. *Optical shop—arranged so that the sequence of work in the development of a lens is carried out from one end of the shop to the other.*

possible to outline a four-year course for optometrists in which these subjects were splendidly cared for. The appointment of Mr. Ernest Petry, dean of the former Rochester School of Optometry, to have charge of the work in optometric practice, of Mr. H. E. Wilder as instructor in optical shop work and the recent appointment of Dr. Jobe Sedwick to give the instruction in the anatomy of the eye has rounded out the staff in this department.

The optical shop is equipped not only for the requirements of the course in optometry but for general precision optics as well. Three courses are given, two of which are specified in optometry and the third designed especially for those majoring in industrial optics.

In connection with the development of the research program of the Institute there will be available a limited number of research fellowships. A bulletin of the work of the Institute is available and it is hoped that this statement of the purposes of its organization and the summary here given of the progress already attained may be of value to those interested in the development of optics in America.

ANNUAL REPORT OF THE SECRETARY OF THE OPTICAL SOCIETY OF AMERICA FOR THE CALENDAR YEAR 1929

MEMBERSHIP RECORD
JANUARY 1, 1929 TO JANUARY 1, 1930

	Honorary	*Regular Annual Payment*	*Regular Life Payment*	*Associate Individual Annual Payment*	*Associate Corporation*	*Total*
Membership as of record in the books of the Secretary and Treasurer 1–1–29*	6	322	8	152	6	494*
Gains during 1929						
By reelection as of 1–1–29	0	1	0	1	0	2+
By election as of 1–1–29	0	0	0	81	9	90+
By election as of 7–1–29	0	0	0	2	0	2+
By replacement 3–14–29	1†	0	0	0	0	1+
Losses during 1929						
By death	0	1	0	1	0	2−
By resignation as of 1–1–29	0	1	0	3	0	4−
By separation for non-payment of dues	0	0	0	2	0	2−
By replacement 3–14–29	1	0	0	0	0	1−
Membership as of Record 12–31–29	6†	321	8	230	15	580†
Gains						
Between 12–31–29 and 1–1–30						
By reelection during 1929 as of 1–1–30	0	0	0	2	0	2+
By election during 1929 as of 1–1–30	0	0	0	91	0	91+
By transfer 10–26–29 as of 1–1–30	0	89	0	0	0	89+
Losses						
Between 12–31–29 and 1–1–30						
By transfer 10–26–29 as of 1–1–30	0	0	0	89	0	89−
By resignation during 1929 as of 12–31–29	0	7	0	4	0	11−
Membership as of Record 1–1–30	6†	403	8	230	15	662†
Counted twice†						1−
						661

* These figures do not agree exactly with those reported in J.O.S.A. *18*, No. 6, 446, June, 1929. A complete check of the records showed minor discrepancies.

† Frank Twyman, President of the Optical Society of London is a regular member(84R) and ex-officio honorary member during his term of office.

Reelected as Regular in 1929 as of January 1, 1929

Selig Hecht (648 R)

Reelected during 1929 as of January 1, 1929

Henry Theodore Wensel (657 R)

Elected during 1929 as of January 1, 1929

Francis Heed Adler (677 R)
Walter Edward Albertson (642 A)
Harold L. Alden (711 R)
Arthur John Ames (696 R)
Robert Fleming Arnott (698 R)
John M. Arthur (683 R)
A. Latham Baker (697 R)
Harold R. Barnes (663 A)
Carl L. Bausch (681 R)
William Otis Beal (687 A)
William Berry (675 R)
Wilfrid Blackham (668 A)
Nathan H. Brachman (649 R)
Ben J. Campbell (626 A)
Barnett Cohen (690 A)
W. J. Crozier (682 R)
Harry R. DeSilva (701 R)
Arthur F. Dittmer (623 A)
William L. Dolley, Jr. (699 R)
Carl Z. Draves (652 R)
Frank E. Duckwall (636 A)
Theodore M. Edison (706 R)
Harry Engwicht (643 A)
Marion Eppley (625 R)
William H. Eyster (702 A)
Elmer H. Finch (678 A)
Alexander Forbes (673 R)
Frederick E. Fowle (646 R)
Simon H. Gage (710 R)
Arthur G. Hall (705 A)
George H. Hamilton (709 R)
Rudolph Hase (679 A)
Harry Helson (645 R)
Evelyn C. Henderson (622 A)
Cedric Edward Hesthal (651 A)
Kenneth C. D. Hickman (688 R)
Marie A. Hinrichs (695 A)
Leo Hirschberg (655 A)
Frank E. Howard (654 A)
C. W. Kanolt (650 R)
Thomas J. Killian (689 A)
Alfred J. Klapperich (659 A)
Heinrich Klüver (691 R)
Lewis R. Koller (700 R)
Charles R. Larkin (634 A)
William K. Lockhart (658 A)
Frederick W. Lutz (674 R)
W. Wallace McKaig (661 A)
David I. Macht (693 R)
Walter E. Mathewson (713 R)
Harold Mestre (624 A)
Dana P. Mitchell (684 R)
Clement Moran (639 A)
George H. Needham (631 A)
Robert R. Newell (712 R)
Brian O'Brien (680 R)
Franklyn C. W. Olson (640 A)
Robert A. Patterson (670 R)
T. D. Phillips (660 A)
Marcello Pirani (662 R)
Arthur R. Riddle (637 A)
C. W. Robbins (686 A)
William J. Sette (633 A)
William Ewing Shahan (708 R)
Carroll M. Sparrow (641 R)
John L. Spence, Jr. (669 A)
Wayne T. Sproull (632 A)
Charles Gormley Stehle (685 A)
Bernhard Steuer (667 A)
Jean I. Storke (644 A)
Elbridge Z. Stowell (635 A)
George Swikart (666 A)
Joseph W. Tanch (671 A)
Leroy W. Tilton (647 R)
Arthur Clinton Watson (707 A)
Adolfo T. Williams (621 R)
Lucy Wilson (672 R)
George Winchester (653 R)
Frederic A. Woll (664 R)
W. D. Wright (714 R)
G. Wilson Younglove (692 A)

Elected during 1929 as of July 1, 1929

Robert Victor Baud (703 R)
Joseph Razek (704 A)

Replaced R. S. Clay, March 14, 1929 as President, Optical Society of London

Frank Twyman (H)

Corporations elected during 1929 as of January 1, 1929

American Optical Co. (638 AC)
Bell Telephone Lab. Inc. (676 AC)
Central Scientific Co. (627 AC)
Cooper Hewitt Electric Co. (629 AC)
Corning Glass Works (628 AC)
National Lead Company (655 AC)
Spencer Lens Company (715 AC)
Technicolor Motion Picture Corp. (656 AC)
Arthur H. Thomas Co. (630 AC)

Reelected during 1929 as of January 1, 1930

E. O. Dieterich (794 R)
John F. Mohler (793 A)

Elected during 1929 as of January 1, 1930

John G. Albright (726 A)
Francis P. Alles (750 A)
Alvin Klintworth Aster (720 A)
J. B. Austin (798 A)
L. E. Barbrow (736 A)
Vola Price Barton (757 A)
William C. Beller (803 A)
Hugo Benioff (722 A)
Herbert B. Brooks (776 A)
Clarence J. Campbell (753 A)
Edna Carter (755 A)
Siu-Hung Chao (802 A)
Walter L. Cheney (733 A)
Chih Teih Chu (758 A)
L. B. Clark (805 A)
J. P. Cooley (795 A)
Charles A. Corcoran (780 A)
F. H. Crawford (734 R)
Charles Burton Crofutt (785 A)
Harvey L. Curtis (790 A)
Elmer Dershem (804 A)
Alexander L. M. Dingee (725 A)
Herbert Grove Dorsey (694 R)
Thomas E. Doubt (766 A)
E. Gilbert Dymond (769 A)
Mark A. Endore (760 A)
Maurice Ewing (791 A)
Carl F. Eyring (782 A)
E. E. Free (762 A)
Alexander S. Galajikian (740 A)
Frederick L. Gates (789 A)
William C. Geer (767 A)
G. E. Grantham (774 A)
John J. Grebe (717 A)
Ira J. Gwinn (775 A)
E. L. Harrington (768 A)
Kenneth Hartley (777 A)
Alfred C. Haussmann (800 A)
Frederick R. Hirsh, Jr. (747 A)
Samuel O. Hoffman (724 A)
R. M. Holmes (807 A)
B. A. Howlett (731 R)
Emily E. Howson (773 A)
Axel G. Jensen (792 A)
A. L. Johnsrud (737 R)
Olaf M. Jordahl (784 A)
Usaku Kakinuma (748 A)
Vladimir Karapetoff (716 A)
James H. Kelly (759 A)
David A. Keys (801 A)
Rudolf Kingslake (756 A)
Earl M. Lowry (727 R)
Vladimir Paul Lubovich (761 A)
Paul McCorkle (729 A)
Frank C. McDonald (723 A)
A. J. McMaster (719 A)
W. C. McQuarrie (763 A)
James B. Macelwane, S. J. (765 A)
Margaret E. Maltby (781 A)
David W. Mann (743 A)
Milton Marshall (779 A)
Paul E. Martin (787 A)
Frederick A. May (751 A)
George Spencer Monk (783 A)
Parry H. Moon (738 A)
D. W. Morehouse (796 A)
Charles C. Nitchie (742 R)
A. de Forest Palmer (728 R)
A. D. Power (744 A)
Paul Rood (770 A)
Richard Ruedy (771 A)
Ancel St. John (788 A)
William Schriever (772 A)
Myron M. Schwarzschild (764 A)
George R. Sears (718 A)
Herman E. Seemann (778 A)
Raymond S. Seward (797 A)
Francis B. Silsbee (754 A)
O. W. Silvey (806 A)
William Warner Sleator (752 R)
Orrin H. Smith (786 A)
David L. Soltau (746 A)

Joel Stebbins (730 R)
W. W. Stifler (799 A)
Carrington H. Stone (735 A)
H. D. Summers (732 A)
Mrs. Mabel S. Vincent (749 R)
M. R. Wehr (721 A)
George B. Welch (745 A)
Frank Wenner (739 A)
Ziro Yamauti (741 R)

Elected to Regular Membership by Action of the Council, October 26, 1929 as of January 1, 1930

Francis Heed Adler (677 R)
Harold L. Alden (711 R)
Arthur John Ames (696 R)
William D. Appel (599 R)
Robert Fleming Arnott (698 R)
John M. Arthur (683 R)
Fred W. Ashton (593 R)
A. Latham Baker (697 R)
Robert Victor Baud (703 R)
Carl L. Bausch (681 R)
Leo Behr (426 R)
William Berry (675 R)
C. Boeckner (602 R)
Hugh G. Boutell (595 R)
Nathan H. Brachman (649 R)
Herbert J. Brennen (589 R)
J. W. Buchta (463 R)
F. H. Crawford (734 R)
W. J. Crozier (682 R)
Harry R. DeSilva (701 R)
William L. Dolley, Jr. (699 R)
Herbert Grove Dorsey (694 R)
Carl Z. Draves (652 R)
Melville Eastham (391 R)
Theodore M. Edison (706 R)
Marion Eppley (625 R)
Alexander Forbes (673 R)
Frederick E. Fowle (646 R)
Simon H. Gage (710 R)
Anna Estelle Glancy (588 R)
Henry Green (103 R)
George H. Hamilton (709 R)
George S. Haslam (574 R)
Harry Helson (645 R)
Mayo D. Hersey (603 R)
Kenneth C. D. Hickman (688 R)
Henry Harold Higbie (433 R)
B. A. Howlett (731 R)
L. G. Hoxton (592 R)
Curtis Judson Humphreys (613 R)
Felix Jentzsch (441 R)
A. L. Johnsrud (737 R)
Lewis V. Judson (598 R)
C. W. Kanolt (650 R)
Heinrich Klüver (691 R)
Lewis R. Koller (700 R)
Rudolph Meyer Langer (601 R)
Earl M. Lowry (727 R)
Frederick W. Lutz (674 R)
David I. Macht (693 R)
Walter E. Mathewson (713 R)
C. Matsuda (375 R)
Dana P. Mitchell (684 R)
Ralph Holcombe Müller (591 R)
Carleton C. Murdock (620 R)
Robert R. Newell (712 R)
W. W. Nicholas (617 R)
Charles C. Nitchie (742 R)
Brian O'Brien (680 R)
A. de Forest Palmer (728 R)
J. Edward Patterson (117 R)
Robert A. Patterson (670 R)
Marcello Pirani (662 R)
Samuel E. Pond (412 R)
R. H. Ranger (439 R)
Horace C. Richards (618 R)
Samuel H. Roberts (584 R)
Thomas W. Rolph (477 R)
William Ewing Shahan (708 R)
James F. Skogland (606 R)
C. M. Slack (580 R)
William Warner Sleator (752 R)
Louise L. Sloan (387 R)
Carroll M. Sparrow (641 R)
Joel Stebbins (730 R)
Leroy W. Tilton (647 R)
Alfred Traeger (430 R)
Clifford L. Treleaven (543 R)
Frederick Gordon Tutton (581 R)
C. T. Ulrey (521 R)
Mrs. Mabel S. Vincent (749 R)
Paul Weaver (555 R)
Henry Theodore Wensel (657 R)
Adolfo T. Williams (621 R)
Lucy Wilson (672 R)
George Winchester (653 R)
Frederic A. Woll (664 R)
W. D. Wright (714 R)
Ziro Yamauti (741 R)

Deaths during 1929

A. T. Fant (497 A)
E. D. Roe, Jr. (63 R)

Resignation during 1929 as of January 1, 1929

Charles G. Eichlin (139 A)
Israel Maizlish (388 A)
Robert Thomas Morrison (197 A)
John C. Shedd (409 R)

Resignations in 1929 as of December 31, 1929

S. F. Acree (612 A)
William Otis Beal (587 A)
Francis E. Cady (392 R)
John G. Capstaff (32 R)
Alfred Cowan (447 R)
M. Katherine Frehafer (178 R)
Ralph E. Lee (587 A)
Miriam E. O'Brien (386 A)
Gilbert J. Palen (77 R)
E. P. T. Tyndall (260 R)
J. H. Van Vleck (476 R)

(Signed) L. B. TUCKERMAN
Secretary

ANNUAL REPORT OF THE SECRETARY OF THE OPTICAL SOCIETY OF AMERICA FOR THE CALENDAR YEAR 1930

MEMBERSHIP RECORD
JANUARY 1, 1930 TO JANUARY 1, 1931

	Honorary	*Regular Annual Payment*	*Regular Life Payment*	*Associate Individual Annual Payment*	*Associate Corporation*	*Total*
Membership as of record in the books of the Secretary and Treasurer 1–1–30..	6*	403	8	230	15	662*
Gains during 1930						
By reelection as of 1–1–30.....	0	0	0	1	0	1+
By election as of 1–1–30.....	0	0	0	51	0	51+
By reinstatement.....	0	0	0	1	0	1+
Losses during 1930						
By death	0	4	0	1	0	5–
By resignation as of 1–1–30.....	0	2	0	3	0	5–
By separation for non-payment of dues..	0	3	0	6	0	9–
Membership as of record 12–31–30.....	6*	394	8	273	15	696*
Gains						
Between 12–31–30 and 1–1–31						
By reelection during 1930 as of 1–1–31..	0	0	0	1	0	1+
By election during 1930 as of 1–1–31...	0	0	0	7	0	7+
By transfer 10–31–30 as of 1–1–31.....	0	40	0	0	0	40+
Losses						
Between 12–31–30 and 1–1–31						
By transfer 10–31–30 as of 1–1–31.....	0	0	0	40	0	40–
By resignation during 1930 as of 12–31–30	0	8	0	2	0	10–
Membership as of record 1–1–31.....	6*	426	8	239	15	694*
Counted twice*.....						1–
						693

* Frank Twyman, President of the Optical Society of London, is a regular member (84R) and ex-officio Honorary Member during his term of office.

Reelected during 1930 as of January 1, 1930

William F. Roeser (835 R)

Elected during 1930 as of January 1, 1930

Gyanendra Nath Banerjee (851 A)
Boyd W. Bartlett (828 A)
Harold F. Bennett (829 A)
Frederick S. Brackett (844 R)
Arthur Bramley (817 R)
Clement D. Child (820 R)
C. C. Cole (821 A)
William Edward Curtis (833 R)
John R. Dunning (845 A)
Harold J. Eckweiler (860 A)
Roger Shepherd Estey (848 A)
H. E. Farnsworth (840 R)
Charles G. Ferrari (839 A)
A. L. Fitch (808 A)
Alice W. Foster (855 A)
Frank Arthur Geldard (857 R)
I. H. Godlove (858 R)
George H. Henderson (814 A)
Kang Fuh Hu (846 A)
Arthur L. Ingalls (865 A)
Serge A. Korff (823 A)
Fred Landon (824 A)
John Y. Lee (834 A)
Oliver C. Lester (843 A)
Lester C. Lewis (818 A)
R. E. Loving (825 A)
Louis R. Maxwell (838 A)
Charles F. Mercer (830 A)
Edwin Morrison (810 A)
Montford Morrison (847 A)
W. S. Nelms (850 A)
Alex. McLean Nicolson (832 A)
J. Rud Nielsen (831 R)
Saburo Numakura (813 A)
Roy Charles A. Nurnberg (852 A)
Philip Pollack (811 A)
Louis G. Pooler (809 A)
C. V. Raman (836 R)
Dorus P. Randall (826 A)
H. K. Richardson (854 A)
Norman Ricker (819 A)
Yale Kirby Roots (837 A)
Willard L. Severinghaus (812 R)
Albert E. Shaw (849 A)
Leland B. Snoddy (859 A)
Roy C. Spencer (815 A)
Verne Frank Swaim (841 A)
Toshio Takamine (816 A)
Albert S. Walton (842 A)
David T. Wilber (827 R)
P. I. Wold (822 R)

Reelected during 1930 as of January 1, 1931

E. P. T. Tyndall (853 R)

Elected during 1930 as of January 1, 1931

William T. Bumsted (863 A)
Paul Harrison Dike (862 R)
Aaron Levin (866 A)
Elbert M. Shelton (864 A)
James Stokley (861 R)
Dayton Ulrey (867 A)
William W. Watson (856 R)

Elected to Regular Membership by Action of the Council, October 31, 1930
Effective January 1, 1931

J. B. Austin (798 R)
L. E. Barbrow (736 R)
Frederick S. Brackett (844 R)
Arthur Bramley (817 R)
Frederick Lyons Brown (597 R)
Edna Carter (755 R)
Clement D. Child (820 R)
William Edward Curtis (833 R)
Elmer Dershem (804 R)
E. O. Dieterich (794 R)
Paul Harrison Dike (862 R)
Thomas E. Doubt (766 R)
Frank E. Duckwall (636 R)
John C. Duncan (578 R)
H. E. Farnsworth (840 R)
E. E. Free (762 R)
Frederick L. Gates (789 R)
William C. Geer (767 R)
Frank Arthur Geldard (857 R)
I. H. Godlove (858 R)
Vincent C. Hall (453 R)
David A. Keys (801 R)

Rudolf Kingslake (756 R)
Vladimir Paul Lubovich (761 R)
W. C. McQuarrie (763 R)
W. A. Marrison (479 R)
George Spencer Monk (783 R)
D. W. Morehouse (796 R)
J. Rud Nielsen (831 R)
C. V. Raman (836 R)
William F. Roeser (835 R)
F. F. Rupert (567 R)
Ancel St. John (788 R)
Willard L. Severinghaus (812 R)
James Stokley (861 R)
Clifton M. Tuttle (424 R)
E. P. T. Tyndall (853 R)
William W. Watson (856 R)
David T. Wilber (827 R)
P. I. Wold (822 R)

Deaths during 1930

Emile R. Cramer (154 R)
Lewis E. Jewell (177 R)
Christine Ladd-Franklin (118 R)
John F. Mohler (793 A) (340 R)
Frederic Gordon Tutton (581 R)

Resignations during 1930 as of January 1, 1930

Leland S. Barnes (546 A)
Emory Hill (353 A)
W. Orland Lytle (182 R)
Thomas P. Pendleton (230 R)
Walter H. Stainton (408 A)

Resignations during 1930 as of December 31, 1930

Fred W. Ashton (593 R)
Hugh G. Boutell (595 R)
Francis Heed Adler (677 R)
A. Latham Baker (697 R)
E. Leon Chaffee (249 R)
Mayo D. Hersey (603 R)
Enoch Karrer (107 R)
Walter B. Lancaster (16 R)
E W. Skinner (516 A)
G. Wilson Younglove (692 A)

(Signed) L. B. TUCKERMAN
Secretary

Die optischen Instrumente. By Dr. Moritz von Rohr. V+130 pages. Published by Julius Springer, Berlin, 1930.

This is the fourth enlarged edition of an elementary text designed to acquaint the user of an optical instrument with the principles of its design and operation. The book is divided into three chapters of which the first gives a brief treatment of optical imagery, the second describes the eye and correction lenses, and the third presents in turn explanations of the different optical instruments. The principal instruments described are the magnifying lens, the microscope, the telescope, the photographic camera and projection apparatus. Instruments for studying the properties of materials, as for example, the interferometer and the spectrometer, are not included in this treatise.

I. C. GARDNER

Lumière Monochromatique, sa Production et son Emploi en Optique Pratique. By Ch. Fabry. 39 pages. Second edition, 1930, from new plates. Published by Revue d'Optique Théorique et Instrumentale, Paris.

The title has been carefully worded to define, with precision, a specialized and important portion of applied optics. The choice of material to be included in the text has been made with similar precision. As a result, after having read the book, one is surprised to learn that such a wealth of information has been presented lucidly and adequately in only thirty-nine pages. A brief introductory chapter is followed by a description and critical appraisal of the different means by which monochromatic light may be produced. The third chapter (fourteen pages) deals primarily with the application of interferometric methods to the testing of optical surfaces and optical instruments but the initial portion of the treatment is sufficiently general to permit its ready extension to other applications of interferometry. The last two chapters deal briefly with the employment of monochromatic light for the study of the chromatic aberrations of optical systems and of the optical properties of materials respectively. This book is written primarily for one interested in the production or testing of good optical surfaces and its publication should prove a stimulus to the more general introduction of adequate testing procedure in optical work. Although written for this definite purpose the book will prove valuable and interesting to any one who works with monochromatic light or interferometric apparatus.

I. C. GARDNER